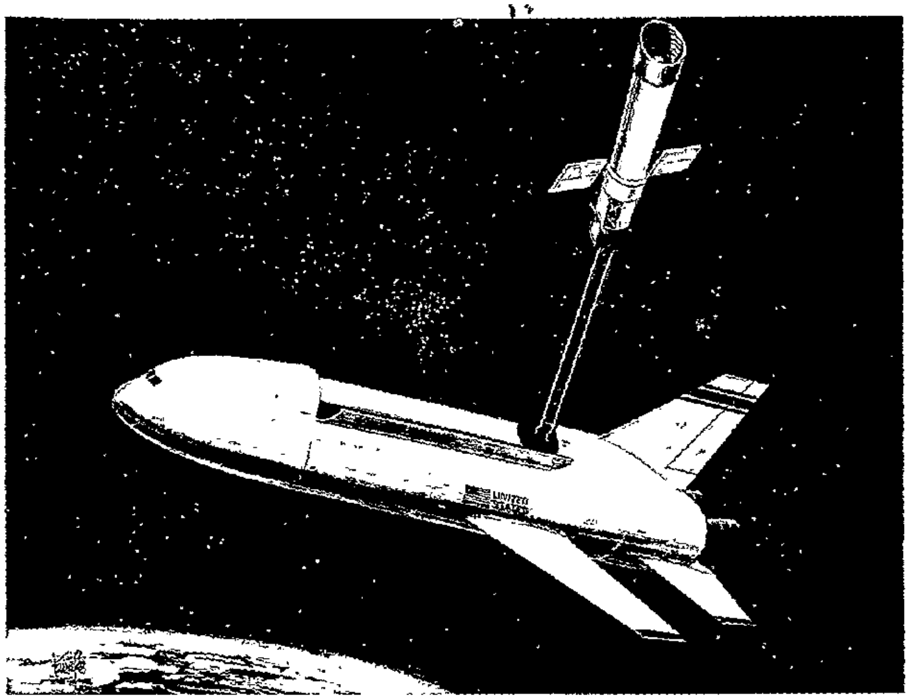

OAO/LST SHUTTLE ECONOMICS STUDY

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center

Contract NAS5-17149

October, 1970

by

GRUMMAN AEROSPACE CORPORATION

VOLUME I

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1.0 INTRODUCTION AND SUMMARY

1.1 STUDY OBJECTIVES AND TASKS

The objectives of this study are twofold. The first objective is to determine the effect of utilizing the Space Shuttle upon the cost of the OAO/LST point design spacecraft. The second objective is to determine the effects of utilization of the Space Shuttle upon the mission objectives and operational modes of the OAO/LST program.

In order to satisfy these objectives, the following study tasks were undertaken:

1. The baseline costs of the OAO/LST point design for the Titan launched program were established.
2. The effects of the Space Shuttle on these baseline costs were identified and assessed.
3. The interrelationships between Shuttle utilization, useful observing time, and OAO/LST program costs were identified and parametrically evaluated.
4. Total program costs for comparative OAO/LST programs with and without the Shuttle were developed.

1.2 STUDY GROUND RULES

The following major study ground rules served as basic assumptions for the study (a more detailed listing of study guidelines and constraints is contained in Section 2 of this report).

1. Use the GSFC "STAR" design for the 120-inch LST design baseline.
2. Assume the shuttle will be available post 1977.
3. Assume a shuttle payload capability of 15' x 60' volume with 30,000 pounds delivered into a 400 N. M 35° orbit.
4. Assume shuttle environment not to exceed conventional launch vehicle operation - retain Titan launch capability.
5. Assume shuttle fleet frequency will be designed to meet the OAO/LST mission model.
6. Use comparable mission models for the Titan and Shuttle based programs as required by the scientific objectives.
7. Use of identical spacecraft for each program except for experiment/telescope changes.

Using these groundrules the study has involved, as one major program element, the generation of a complete cost model of an OAO/LST based on the GSFC point design spacecraft and launched in what has been considered until now the conventional manner employing an expendable booster, the Titan III-D7. This baseline cost model has undergone several iterations based on possible changes resulting from the introduction of the concept of an Earth Orbital Shuttle (EOS) available for initial launch, deployment, resupply, and retrieval.

The effects of this EOS availability on the design and operation of the OAO/LST spacecraft and the resultant sensitivity to program costs has been presented.

1.3 LARGE SPACE TELESCOPE OBJECTIVES

The report "Scientific Uses of the Large Space Telescope", released by the Space Science Board of the National Academy of Sciences in the Fall of 1969 outlines the objectives of space astronomy through the 80's and emphasizes that the needs of the scientific community can no longer be met without providing an LST capability on a continuing basis. This report also provides guidelines for the design of the LST optical system. This guideline has been used in the OAO/LST baseline design. The Astronomy Missions Board in their position paper, "A Long-Range Program in Space Astronomy" published in July 1969, also recommends that a 3 meter large space telescope program be incorporated in planning for the mid 1970's. The AMB report additionally recommends that the LST be evolutionary from the current OAO program. The use of OAO developed subsystems to accomplish the LST mission satisfies the AMB recommendation.

In summary, the objectives of the Large Space Telescope are:

- Extend space astronomy observation capability from 1 meter to 3 meter to examine:
  - Scale and curvature of universe
  - Evolution of galaxies and quasars
  - Density and composition of interstellar matter
  - Structure of asteroids and cometary nuclei
  - Planetary atmospheric and surface structure
  - Composition of stars in neighboring galaxies
  - Physical nature of pulsars
- Maintain this capability for at least a decade to meet the continuous scientific requirements as stated by the National Academy of Sciences
- Be operated as a Multi-Instrumented National Space Observatory in conjunction with ground telescopes and expand participation of the scientific community to insure that the broadest scope of astronomy requirements will be met.

1.4 OAO/LST PERFORMANCE COMPARISON

While ground-based observatories are limited in both resolution and wavelength by the obscuring effects of the earth's atmosphere, the success of the OAO program has provided astronomers with the tools for extensive investigation in the ultra-violet region of the spectrum. The orbiting of diffraction-limited optics, of 3 meter aperture in the LST, will represent as significant an increase in faint limiting magnitude and accompanying

improvement in angular and spectral resolution as the construction of the Mt. Wilson and Palomar facilities did for ground-based observation. It is also important to note that the technical requirements demanded by the LST represent a logical extension of the capabilities developed on the NASA OAO program. These requirements are compared with the OAO Program in the following table.

Table 1-1. OAO/LST Performance Comparison

Characteristics	Ground Based	OAO-2	OAO-B	OAO-C	LST
Aperture	200 inch	1 - 16 inch 4 - 8 inch	38 inch	32 inch	120 inch
Wavelength	3000Å - 10,000Å	1100Å - 4000Å	1100Å - 4000Å	950Å - 3300Å Plus X-Ray	1000Å - 300,000Å
Guidance Stability	±0.5 Arc Sec	±3 Arc Sec	±0.25 Arc Sec	±0.03 Arc Sec	±0.004 Arc Sec
Limiting Star Magnitude	23	10	14	7	29
Instrumentation	IR Visible	Ultra-violet	Ultra-violet	Far Ultra-violet X-Ray	IR Visible Ultra-violet
Size	-	8 Ft Dia 10 Ft Length	8 Ft Dia 10 Ft Length	8 Ft Dia 10 Ft Length	12 Ft Dia 45 Ft Length
Weight	-	4200 Lb	4700 Lb	4800 Lb	22,000 Lb

1.5 SHUTTLE IMPACT ON OAO/LST

This study has also evaluated the use of the Shuttle in a resupply mode and examined the economic influence that this mode would have on the overall program cost of the OAO/LST by considering the following areas:

1. Reduction in the number of OAO/LST's required by:
   - Life extension through subsystem maintenance
   - Avoiding obsolescence by instrumentation update
2. Reduction in the cost of building space hardware since repair capability allows lower MTTF's.

3. Elimination of redundant equipments except as required to guarantee resupply capability.
4. Reduction in the number of spares by retrieval and refurbishment of returned subsystems.

The results of this study impact directly in the areas shown in Figure 1-1, each of which has been broken down into greater levels of detail in this report. In all of the detailed areas, designs and operational plans have been tailored to suit the requirements of cost drivers identified and quantized in this study.

1.6 STUDY RESULTS

The results of the study, comparing OAO/LST program costs with and without shuttle, are summarized in Figure 1-2. These costs reflect a program for continuing astronomy as discussed in paragraph 1.3 and represent 6 spacecraft and 6 Titan launches for the baseline program with 3 spacecraft with 1 Titan and 2 Shuttle launches with 3 additional Shuttle revisits for resupply and experiment changes for the economic comparison of the Shuttle program. Making these experiment changes with the Shuttle program represents a $91 million savings as compared to achieving the same degree of flexibility without the Shuttle. This savings is summarized in Figure 1-3. Comparing the two programs in Figure 1-4 shows that large amounts of additional uptime, or spacecraft operational time, is achieved with the Shuttle program for a small increment in increased costs compared with the large increase in costs required without the Shuttle to gain the same degree of uptime.

Figure 1-5 compares the most important characteristics for the OAO/LST programs with and without the Shuttle. In all cases, the Shuttle enables a higher uptime, lower program cost, and a lower MTTF with its attendant reduction in technological complexity and risk. Although the carpet plot analysis shown in detail in Section 5 shows that a minimum cost program is achieved with a 12 month MTTF satellite, or at current state of the art achievement for MTTF's, we have used a 24 month MTTF satellite for comparative purposes since this satellite will represent some degree of degraded performance and is more consistent with the resultant degraded performance that will accrue to the 36 month MTTF requirement for the OAO/LST program without the Shuttle.

Figure 1-6 has been developed to show the relationship between Shuttle flight cost and the cost of increased satellite MTTF. Considering that each Shuttle revisit adds an increment of life equal to (1) MTTF, the cost of a Shuttle flight may then be compared to the cost of adding (1) MTTF through improved design and production. Since this means doubling the

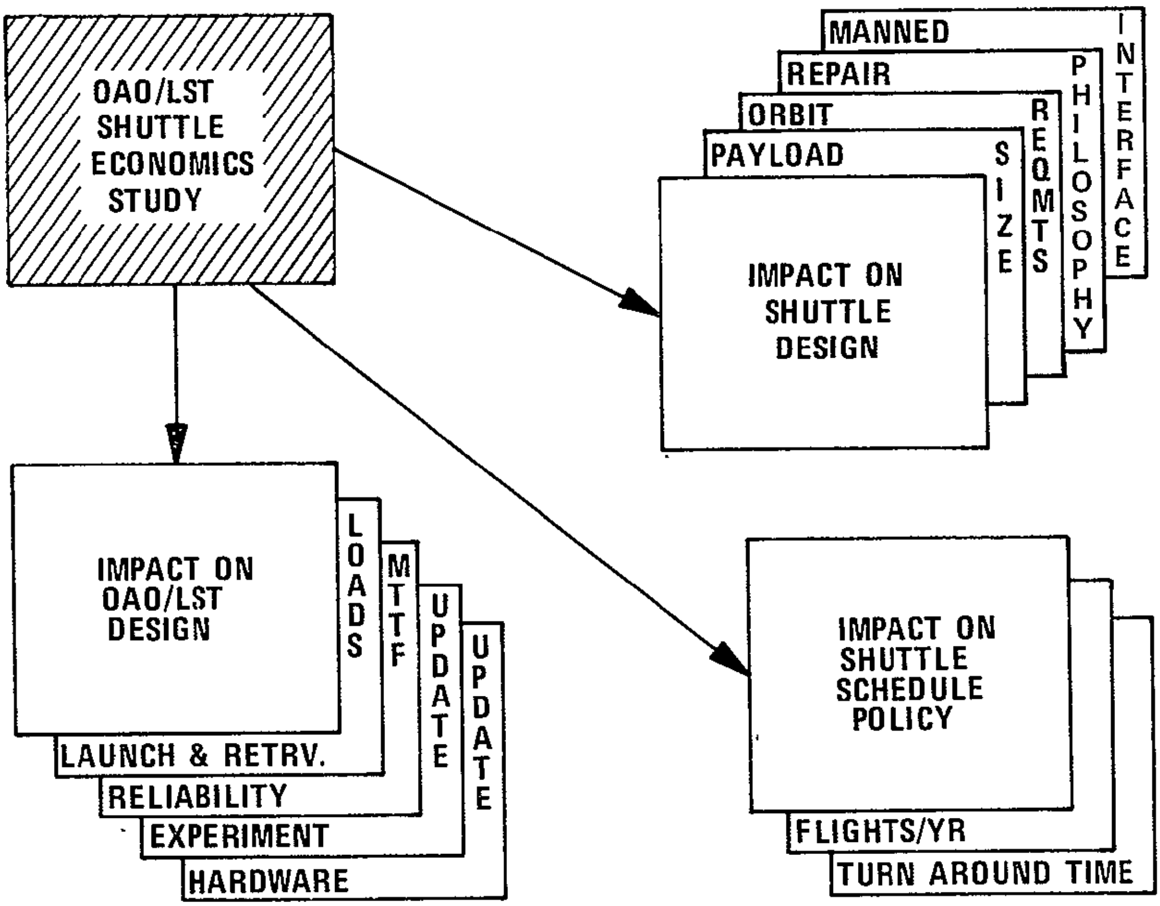


Figure 1-1. OAO/LST Study Impact

	Shuttle, $M		Titan, $M		Savings Total, $M	Savings %
Spacecraft		368		503	137	21
Launch Vehicles – Titan	22.5	(1)	135	(6)		
– Shuttle	25.0	(5)	–			
Resupply Mech – Shuttle	24.5		–			
Subtotal		72.0		135	63	10
Total		440		638	200	31

Figure 1-2. OAO/LST Cost Savings with Shuttle

	Without Shuttle	With Shuttle
Spacecraft	73.6	–
Launch Vehicle	22.5	5.0
Instrumentation	13.0	13.0
Total	$ 109.1 M	$ 18.0 M
Response Time	3 Yr Interval	On Demand
Cost Savings		$ 91.0 M

Figure 1-3. OAO/LST Experiment Change Cost Comparison

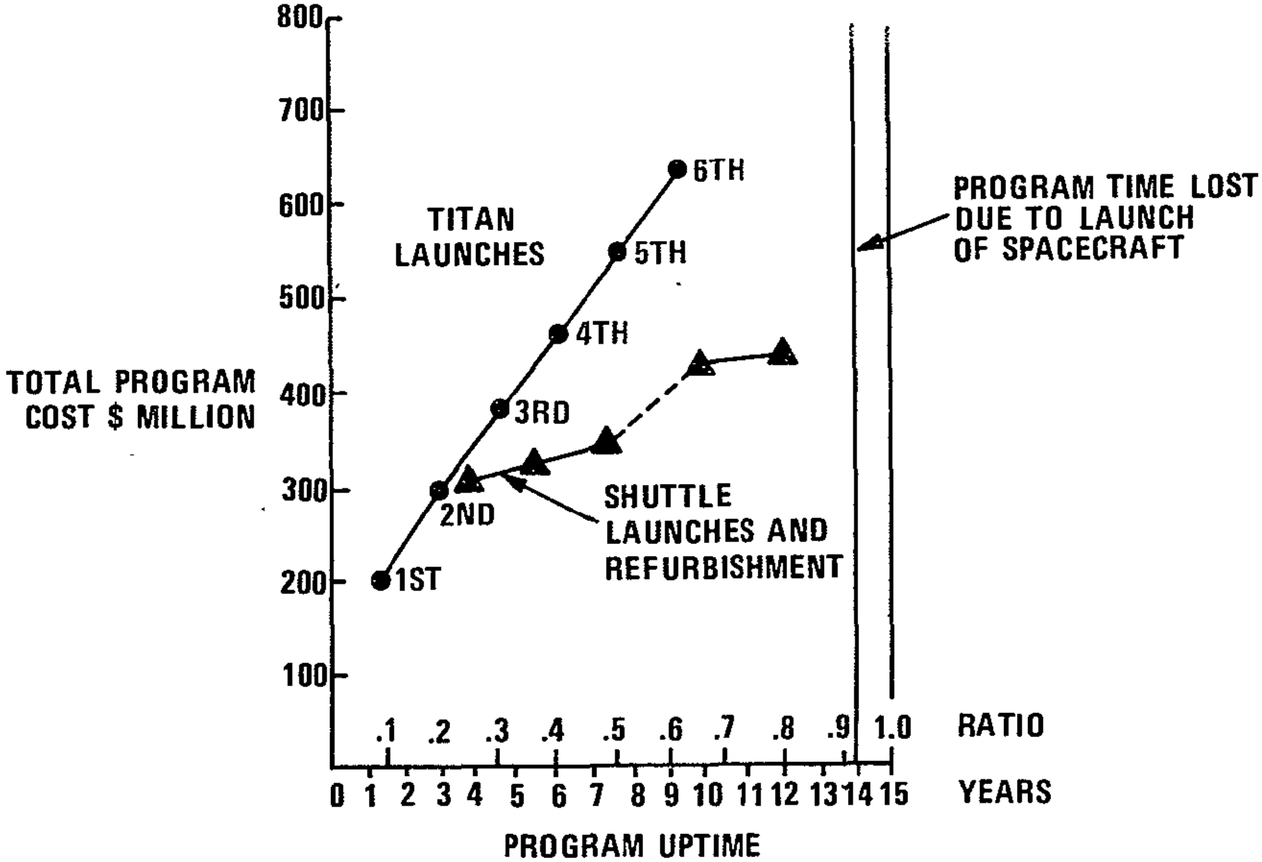


Figure 1-4. OAO/LST Cost Comparison With/W/O Shuttle

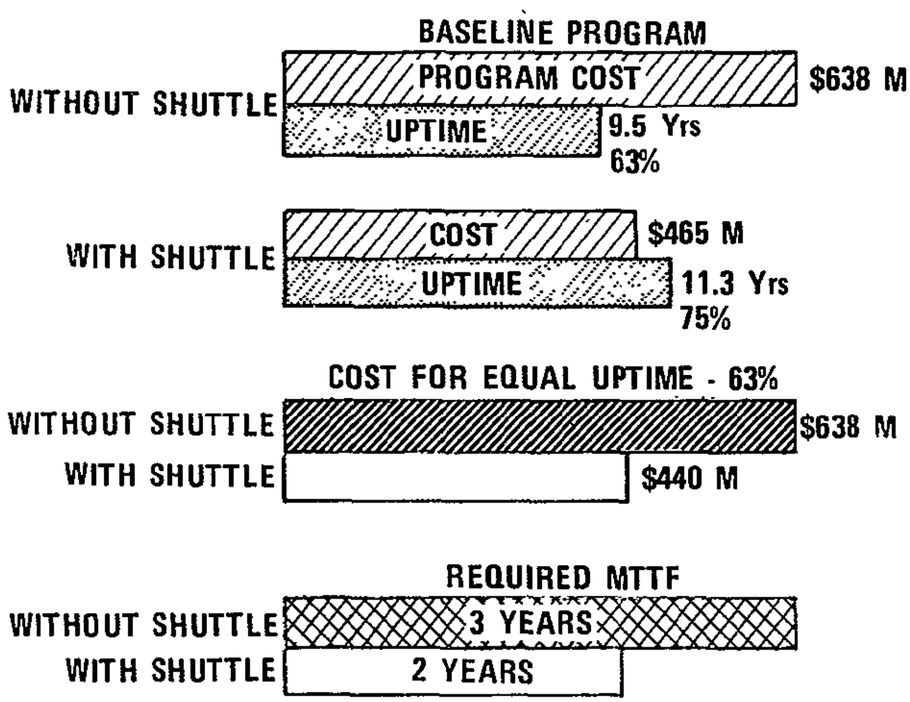


Figure 1-5. OAO/LST Program Comparison

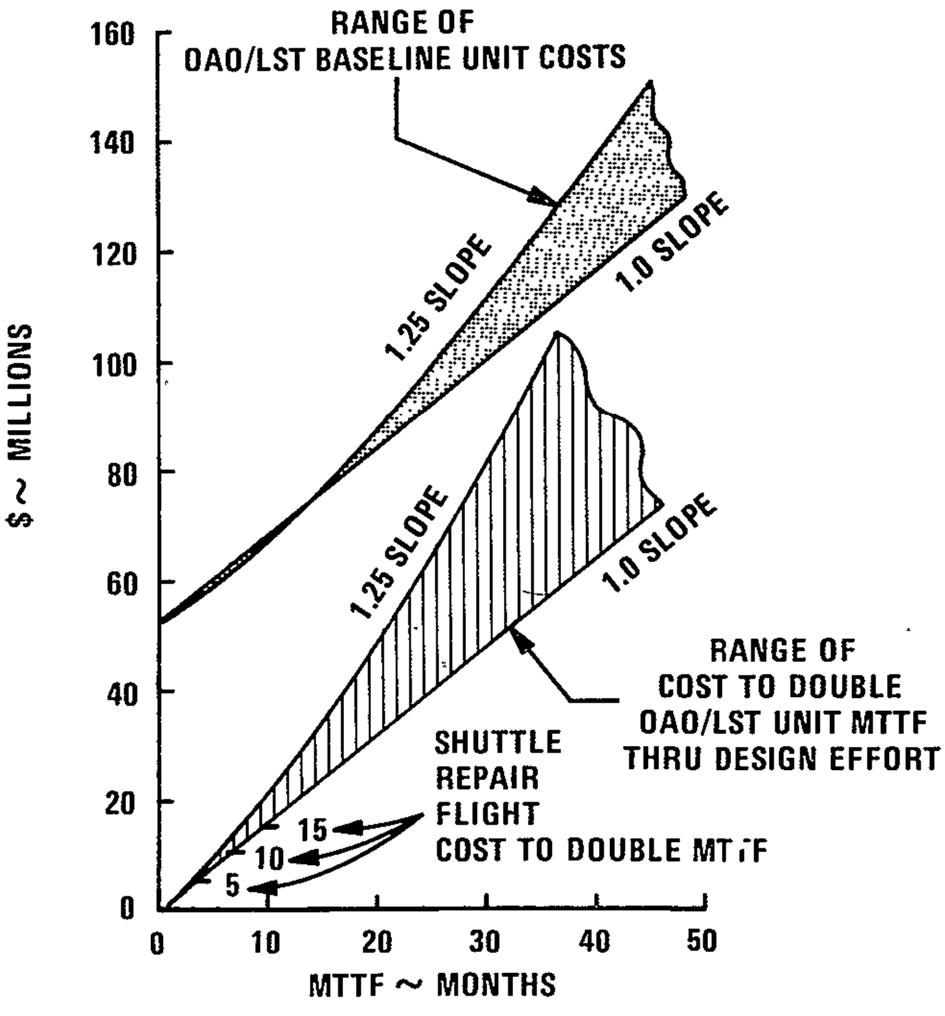


Figure 1-6. Cost Effectiveness of Shuttle Repair

MTTF, the cost to double MTTF was taken from the upper set of curves and plotted to produce the lower set. The addition of various Shuttle flight costs defines levels of MTTF above which use of the Shuttle is economically preferable, and below which improved MTTF through design is best. From Figure 1-6 it can be seen that the Shuttle revisit costs can approach $20 million before it becomes cost effective to improve MTTF through design. This is true regardless of whether we use a 1.25 or a 1.0 power slope. This analysis has shown that the Shuttle program can contribute a cost savings to future spacecraft design and development that goes far beyond the savings that accrue due to the low cost transportation provided.

1.7 STUDY CONCLUSIONS

This study has identified several important economic advantages that will accrue to future scientific spacecraft programs that had not been realized before. In summary these are:

- Spacecraft savings of $137M
- Launch vehicle savings of $63M
- Program savings of $200M
- Shuttle allows experiment change for $91M savings
- Annual funding requirement comparable to OAO program
- Schedule delays of up to 6 months due to Shuttle availability or turnaround time do not significantly affect OAO/LST Program costs
- Shuttle availability makes current spacecraft technology adequate for OAO/LST mission
- Shuttle flight cost can go to $20M before state-of-the-art MTTF improvements become cost effective for today's OAO-LST mission
- Tomorrow's mission requirements can be met with more cost effectiveness through Shuttle repair rather than design improvements for increased MTTF
- Shuttle availability minimizes uncertainties in OAO/LST performance and total program cost
- Low OAO/LST program sensitivity to Shuttle payload capacity
- Increased science capability through instrumentation update
- Orbital resupply enables higher uptime ratios
- Observation cost per year reduced
- The ability to repair failures allows the more demanding missions of the 1970's to be met with existing technology, thereby
  - Allowing initial program estimates to be established with confidence at acceptable levels
  - Preventing cost growth

- Offering management options for cost reductions over prior experience by
  - Reducing the number of missions required
  - Reducing costs by lowering MTTF requirements
  - Re-use of retrieved hardware
- Spacecraft program cost reductions of 27% are achieved for LST based upon existing technology
- Abort capability with Shuttle eliminates mission loss due to spacecraft or L/V failure

1.8 STUDY RECOMMENDATIONS

This study has indicated that a more detailed future effort should be instituted that would examine the economic impact of OAO/LST point design optimization utilizing the shuttle. It is therefore recommended that the following tasks be pursued:

Task 1	Subsystem Level of Redundancy vs. Cost Optimization
Task 2	Subsystem Level of Maintenance Optimization
Task 3	System Dynamic Simulation - To Determine Impact of Design Guidelines
Task 4	Assess Impact of Additional Cost Variables

Task 1 will involve the use of a dynamic programming technique which will evaluate the possible combinations of cost and number of redundant units in each LST subsystem. The program will then select the subsystem design alternative or set of alternatives which produce the greatest probability of success for a given cost.

Task 2 includes the analysis of cost versus the level, (module, blackbox, or subsystem) at which in-space maintaining will be performed. Various levels of maintenance for each LST subsystem will be investigated and their cost impact evaluated to insure that the LST is resupplied at the most cost effective level.

Task 3 will involve an actual simulation of a 15 year LST mission under various resupply, delay, MTTF, level of redundancy, and level of maintenance conditions. This simulation will allow for a cost evaluation of the impact of sets of design guidelines simultaneously.

Task 4 includes an in-depth assessment of the other cost elements as well as the variable costs which were previously assessed. The sensitivity of cost to reductions in MTTF or design life specifications will be quantitatively evaluated. This will include the reduction of design analysis, test and program schedule. The cost savings associated with retrieval and refurbishment, which should be of significance due to the large investment in spacecraft and telescope cost elements, will also be evaluated in this task.

2.0 BASELINE OAO/LST

2.1 THE BASELINE PROGRAMS AND COSTING GROUNDRULES

The spacecraft used as a base for this study were based upon a Goddard supplied point design of the Large Space Telescope (LST). For the purposes of this study the Goddard designed spacecraft was used without any changes since it represents a logical step by step technical evolution from current OAO experience. The optimization of this design was not a study objective. This baseline design is the same as that introduced by Goddard in the June 1969 presentation, "Space Astronomy at the Crossroads", with certain evolutions as developed by the Goddard LST Project during the past year incorporated.

Two baseline LST programs have been selected to provide a reference for evaluation of alternative options in order to assess the economic impact of the Shuttle (EOS) on the space astronomy mission over the next decade. The baseline program without shuttle utilizes conventional launch equipment, the Titan III D7 vehicle, with no provision for repair in orbit capability. For economic cost comparison, an alternative LST program has been evaluated with shuttle launch capability and comparable to the Titan program in experiment payload effectiveness and life in orbit. The two programs and their mission models are indicated in Figure 2-1. Spacecraft for the two programs were assumed to be identical. Experiment instrumentation varies for each flight. To meet the objectives of the Large Space Telescope program, as recommended by the National Academy of Science, requires a program for continuing astronomy as outlined in Figure 2-1.

2.1.1 OAO/LST - Without Shuttle

This program comprises a six vehicle program with first launch in 1977, assuming a hardware start in mid-1972. OAO technology has been used with the resultant reduction in development costs together with a projected moderate increase in unattended orbital life over present capability without large additional expenditures for an increase in mean time to failure (MTTF) of the vehicle as a whole.

The first three vehicles in the program are on two year spacings, with expectation of technology improvement primarily in the telescope optics area. The latter three vehicles, on three year spacings, are expected to incorporate diffraction limited optics by building on the experience in orbit of the first three LST's.

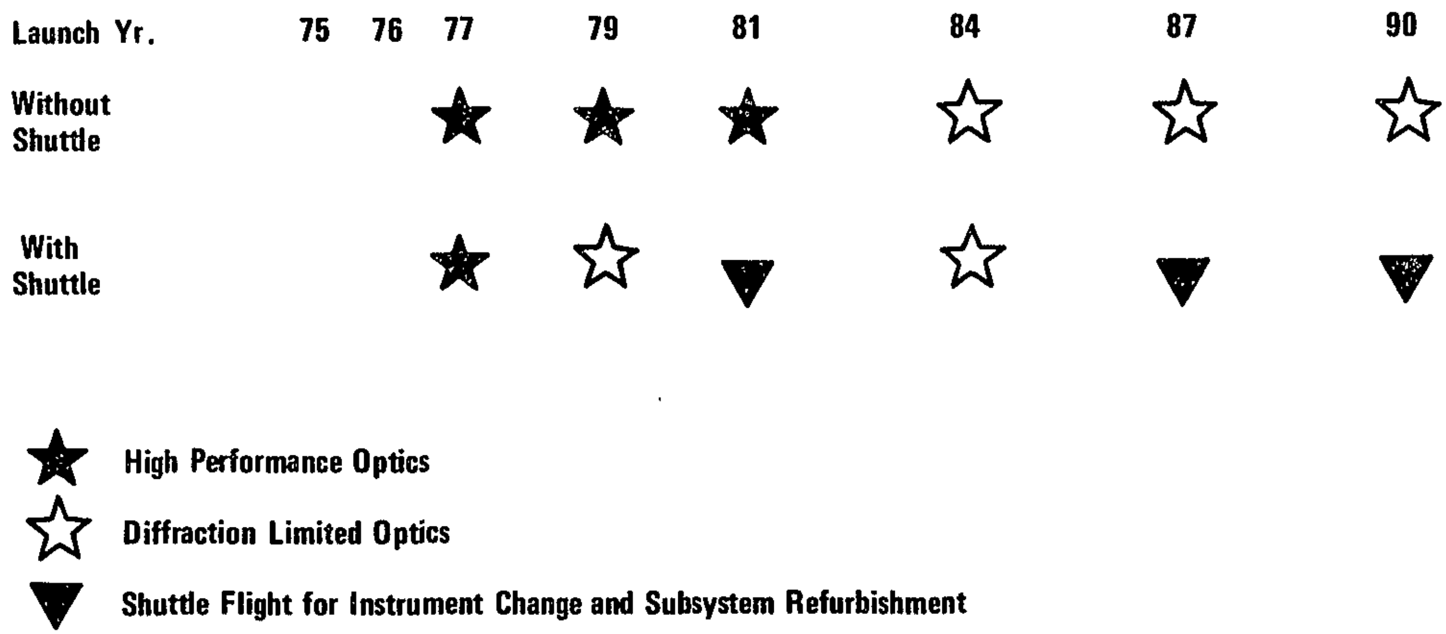


Figure 2-1. Alternate Approaches to Meet OAO/LST Objectives

The astronomical experiment packages are considered to vary for each vehicle in the baseline program. This will provide for updating of scientific instrumentation to keep the payload technology current, such as incorporating newly developed detectors, and for redesigned experiments to take advantage of new astronomical information gained from previous flights.

2.1.2 OAO/LST - With Shuttle

With the existence of the Shuttle, visitation in orbit for maintenance and update becomes possible. Three spacecraft are projected for this program instead of six as with the baseline OAO/LST. The first launch of the shuttle program, however, is by Titan on the assumption that the shuttle will not be operational prior to 1978. On the second launch, by shuttle, in-orbit check-out and adjustment of the LST optical system will be possible prior to its release from the shuttle. The experience of the first vehicle together with in-orbit testing insures that diffraction limited performance can be reached sooner than with the baseline program.

The Shuttle OAO/LST program matches the baseline program in orbital life and effectiveness for the purpose of comparing costs. The LST's have the same unattended life whether launched by Shuttle or Titan, and it is considered that a shuttle visit restores the LST orbital life expectation to its value at launch. Thus three shuttle visits to vehicles 2 and 3 would produce the same uptime as with the six Titan launched vehicles, unattended. Moreover, the three visits combined with the three shuttle launched vehicles make six changes of experiment packages possible. In this way, the shuttle program may be considered equivalent to the Titan program in scientific effectiveness. However, mission life specified for the Titan program includes degraded performance.

The shuttle supported LST program can produce a large variation in both overall cost and effectiveness. A prime purpose of this study is to analyze these variations in a systematic way, in order to arrive at the most cost effective shuttle program.

2.1.3 Costing Groundrules

The groundrules for costing use 1970 constant dollars as the economic measure. A point design for the LST was provided by GSFC as the spacecraft cost baseline. For all flights, in each of the OAO/LST Program with and without the shuttle, the spacecraft subsystems and the telescope components are identical.

The point design cost is minimized by making maximum use of technology developed in the OAO program, particularly in the LST subsystems where much of the OAO technology is directly applicable. In this way, a major portion of the development costs invested in the OAO program are saved in the LST program. Specific areas of applicable OAO technology are discussed in the point design description. Much of the cost experience of the OAO program is also applicable to the GSFC LST point design. As a result, the cost figures generated are on a much firmer ground than would otherwise be possible. Wherever applicable, the cost experience of the OAO is separately displayed for comparison with the LST estimated costs.

In the production of the LST, major integration operations and systems testing will be performed at Goddard. Integration will consist of flight hardware components of the vehicle in place. Emphasis will be placed on operation of primary optics and experiment packages with the spacecraft subsystems. Development integration will have been accomplished at the contractor facility, using simulated experiment interfaces as necessary. Major through-put acceptance testing, such as thermal-vacuum, will also be performed at Goddard. Contractors assistance will be furnished as required for the GSFC integration and test activities.

A significant groundrule adopted for costing of the shuttle supported program was to free the LST from costly "man-rating" requirements as found in the man-attended and man-inhabited spacecraft programs. Accordingly, in orbit modular exchange on the shuttle supported LST is designed to be accomplished by a remote manipulator. In this way there will be no manned contact with the LST and therefore the design of the LST does not affect crew safety. Another advantage is the capability of the manipulator to handle modules far larger and heavier than a man could handle, even under weightless conditions.

Numerous problems must also be solved in the development of a spaceworthy manipulator. The technique and mechanizations of precise positioning and holding of the modules in place on the LST is a major problem. A development cost for the remote manipulator of $25 million has been generated using GSFC supplied drawings and sketches and using LM and Apollo cost factors for precise mechanisms. This cost has been included as one of the economic factors in the shuttle program.

An important economic factor is the cost of shuttle service flights which is assumed as $5 million per flight. Variation of this figure is desirable since the actual cost is not yet known. Moreover the study will show that the OAO/LST Program has a low sensitivity to variation in shuttle flight costs.

The general groundrules are summarized in Table 2-1, and shuttle-peculiar groundrules in Table 2-2.

In addition, the following assumptions were made:

- The LST baseline design is provided by GSFC in the form of layout drawings, specifications, and analysis. Engineering effort is required for conversion of the design to detail drawings for manufacture.
- Spare parts will be provided on the premise that components of later flight articles in the program can serve as replacements in the earlier articles. Such components, if used, would be remanufactured or refurbished from the unsuitable earlier components.
- In the shuttle program, four sets of replaceable subsystem modules will be manufactured for the three flight articles, providing one spare set. Thus for two vehicles in space, two sets of modules will be on the ground, at least one of which will be ready for orbital replacement while the other is being repaired.
- The cost of repair, test and checkout of subsystem modules has not been costed. These modules will be repaired on a time and material contract as required
- Shuttle interface costs include a hard line communications link from GSFC to MSC, as well as the data link from GSFC to the spacecraft.
- In both the Titan and Shuttle supported programs, the first vehicle to be manufactured will be a structural test article, subjected to development and qualifications testing. It will then be refurbished to comprise the last flight vehicle of the program. This philosophy also applies to subsystem and component levels.

Table 2-1. OAO/LST Pricing Groundrules

- 1970 Constant Dollars
- OAO/LST Baseline - Without Shuttle
- GSFC/LST Point Design
- Titan III D7 Launch Vehicle
- Integration & Test at GSFC - Contractor Support
- Spacecraft & Telescope Same for all Missions
- New Astronomical Instruments each Flight
- Pricing Based on OAO Cost Experience

Table 2-1. OAO/LST Pricing Groundrules (Cont.)

- Telescope & Instrumentation Cost Supplied By GSFC
- Maximum Use of OAO Equipment & Technology to Reduce Developmental Costs
- Prototype Shop Operations - Centralized Facility

Table 2-2. OAO/LST Pricing Groundrules - Shuttle

- No Manrating of LST Required
- 25 M Development Cost for Remote Manipulator
- 5 M Shuttle Operation Cost
- 3 Additional Shuttle Flights Required to provide Equivalent Science and Extended Life

2.2 THE BASELINE DESIGN

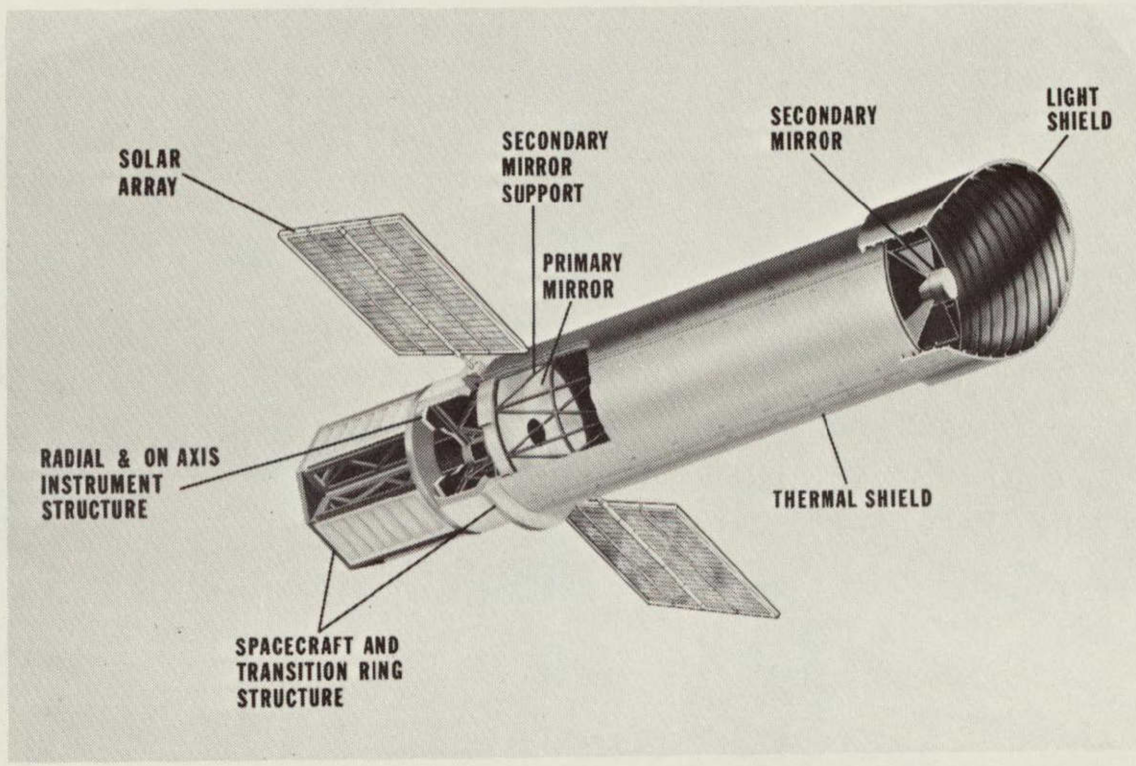
The point design for the LST, provided by GSFC, is illustrated in Figure 2-2. The vehicle is approximately 13 feet in diameter, 45 feet long, and weighs approximately 22,000 lbs. It incorporates a Cassegrainian telescope arrangement, with a 120 in diameter primary mirror. The instrument compartment, behind the primary mirror, contains five separate instrument packages operating in the focal plane of the telescope. Four of the five are experiment groups for scientific information; the fifth is an offset tracker which is functionally part of the stabilization and control system. Each of these five packages is replaceable in orbit in the shuttle supported LST, but is permanently installed in the Titan version.

Behind the instrument compartment is the spacecraft structure proper, housing the subsystems serving the entire vehicle. These are four in number, each housed in a separate replaceable-in-orbit package, on an entire subsystem basis. The subsystems comprise the stabilization and control, communication and data handling, pneumatics, and electrical power. In the case of the Titan launched LST, the subsystems packages are permanently fastened in place.

2.2.1 Description of Baseline LST Structure

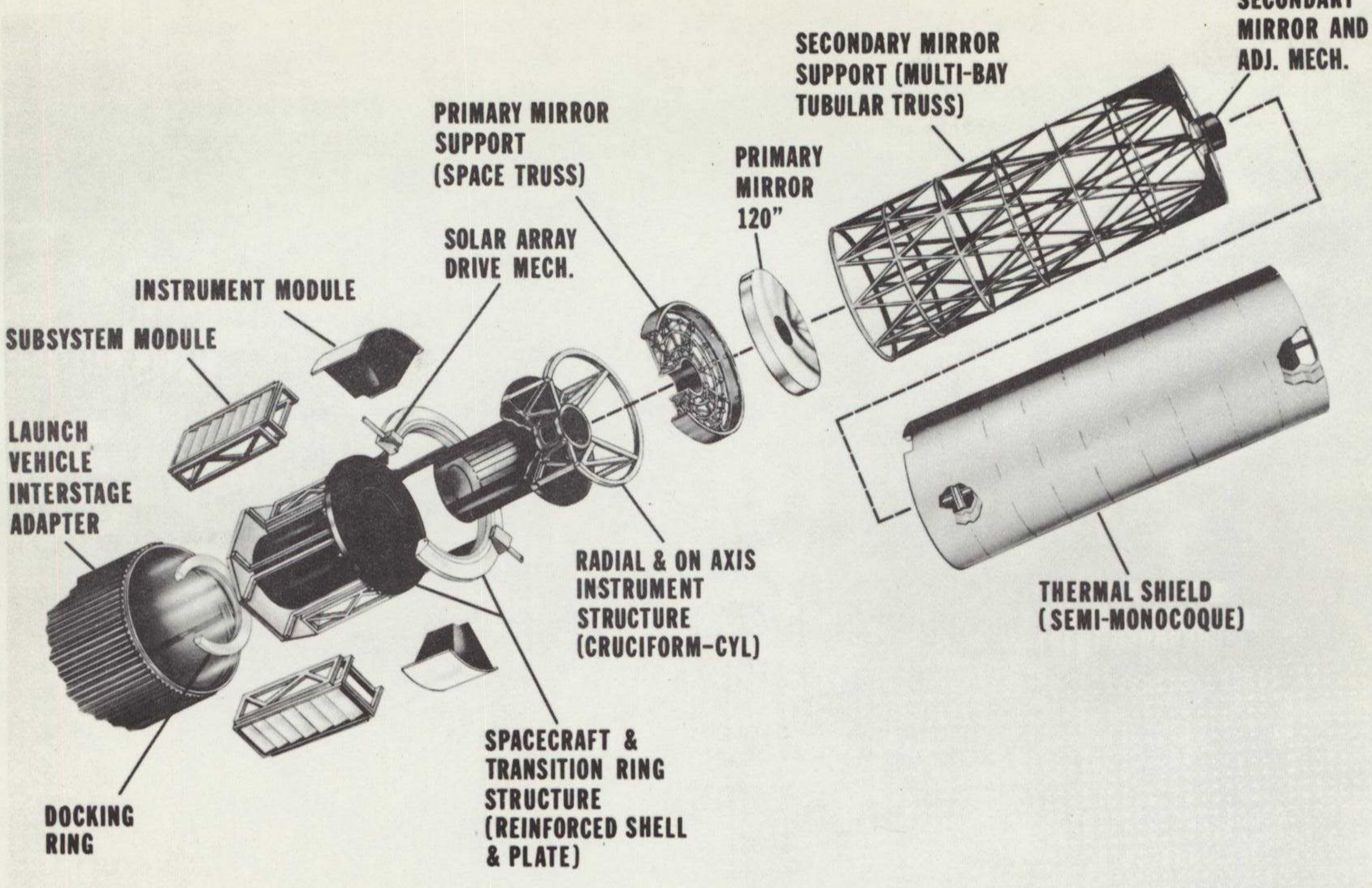
The structural concept of the LST point design is shown in Figure 2-3. Detail descriptions of the individual structures are given in Ref. (1). Various concepts were examined and those chosen are briefly described below. Figure 2-3 shows the location of each structure in the total vehicle.

Ref. (1.) O'Connor, J.W., et al. "Structural Designs for a 120-Inch Diameter Advanced Orbiting Telescope" Goddard Space Flight Center Report X-284-70-147, April 1970.



SUPPLIED BY GSFC

Figure 2-2. Large Space Telescope Structural Composite



SUPPLIED BY GSFC

Figure 2-3. 3 Meter Large Space Telescope Structural Concept

GSFC has designed the structure of the LST for Titan III D-7 Launch, with a Viking shroud (150 in. I. D. X 56 ft.) Qualification design loadings are:

10g Compression (Vertical Launch)	23 HZ
5g Tension	
5g Lateral	5- 7 HZ

The Titan g-loadings are within the above figures.

The LST structure comprises five individual structures: (1) thermal shield, (2) secondary mirror support, (3) radial and on-axis instrument support, (4) primary mirror support, (5) spacecraft and transition ring structure.

2.2.1.1 Thermal Shield

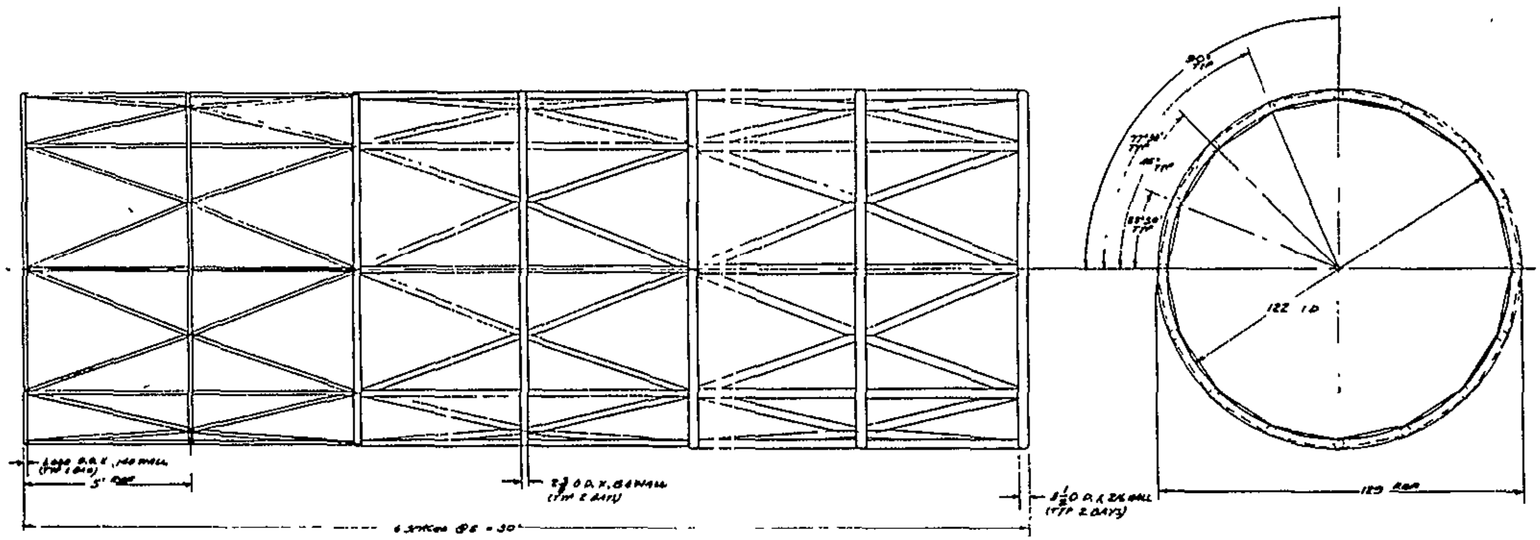
The shield is a one-piece skin, of aluminum, with integral stiffening by machining from the solid. The skin remaining is .080 in., with stiffening longerons and rings extending approximately 1-1/2 inch internally. Heat pipes, circumferential only, are welded on the outside of the structure. The outer skin is silver backed teflon or ALZAK, as required. The weight of the shield is 1060 lbs. Further description is given in pp. 20-25 of Ref. (1).

2.2.1.2 Secondary Mirror Support Structure - Figure 2-4

The structure is a cylindrical shaped space truss, three hundred sixty (360) inches long and one hundred twenty nine (129) inches outside diameter.

The member sizes are lightest at the upper (secondary mirror) end of the truss (left hand side of Figure 2-4) and increase in size toward the base end (near the primary mirror). This "tapering" of members has the advantages of both reducing the bending moment stress and reducing the weight of the structure.

There are no discontinuous members in the truss. Lateral shear loads are carried by rings to truss points along the structure. Each member is a straight tube of circular cross section within each bay. The member sizes range from three and one half (3-1/2) inches outside diameter at the base to one (1.0) inch diameter at the upper end. The member wall thicknesses varied from 0.216 inches thick at the base to a 0.140 inch thick wall at the upper end. Although circular cross-sectioned members are tentatively specified, rectangular



SUPPLIED BY GSFC

Figure 2-4. Secondary Mirror Support 6 Section Space Truss

cross-sectioned members may be substituted to simplify intersections when joint details are designed.

The structure is all titanium (Ti-6Al-4V) and weighs 2400 lbs.

2.2.1.3 Primary Mirror Support Structure - Figure 2-5

The central design concept is that the primary mirror support points are to move downward in the same plane during launch acceleration so as not to deform the mirror (uniform deflection). The 27 mirror support points are held in air chucks during launch as shown in Figure 19, Reference (1). In orbit, these are released and another 6 energized. Three will be radial and three will be edge located. The three radial support points will be adjustable by piezo-electric stack drivers, described on P. 42 and Figure 21 of Reference 1, to compensate for differential thermal expansion of the mirror and support.

The structure has nine open trusses subtended about a central hub. The outboard end of each truss is supported by a deep circular support ring. Eighteen support points are mounted on each radial truss while the remaining nine support points are mounted on intermediate trusses. The unshaded small circles of Figure 2-5 indicate the support points for the mirror during launch while the dark shaded circles represent passive support points for the orbital phase of the mission. Lateral restraint is offered by passive supports shown around the periphery of the large support ring.

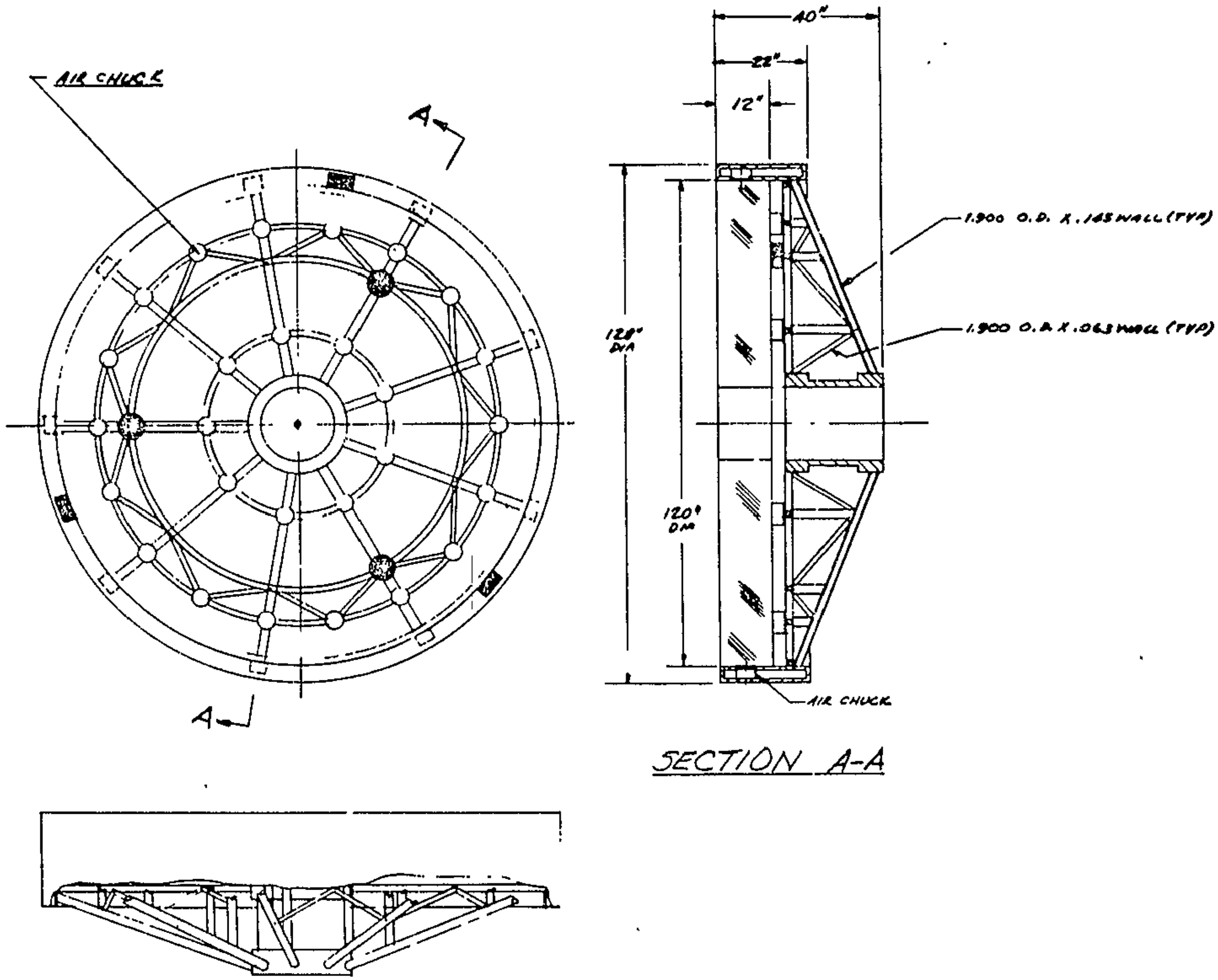
The structure is all titanium and weighs approximately 2300 lbs. The mirror support mechanism weighs approximately 400 lbs.

2.2.1.4 Radial and On-Axis Instrument Structure - Figure 2-6

This structure is all titanium and weighs 1300 lbs. The large baseplate is a thermal plate with circumferential heat pipes, designed to smooth out thermal gradients due to unequal heat loads from instrumentation. Further description of the structure is given on pp. 26-31 of Reference (1).

2.2.1.5 Spacecraft and Transition Ring Structure - Figure 2-7

Concept "G" shows the structure in outline. The transition ring is a basic structure to which the telescope and experiments are attached at the forward end, the spacecraft structure at the aft end, and to which the launch interstage adapter connects. It is also a hard point for support in the shuttle, providing the required structural interface with the shuttle cargo bay.



SUPPLIED BY GSFC

Figure 2-5. Mirror Support Tapered Space Truss

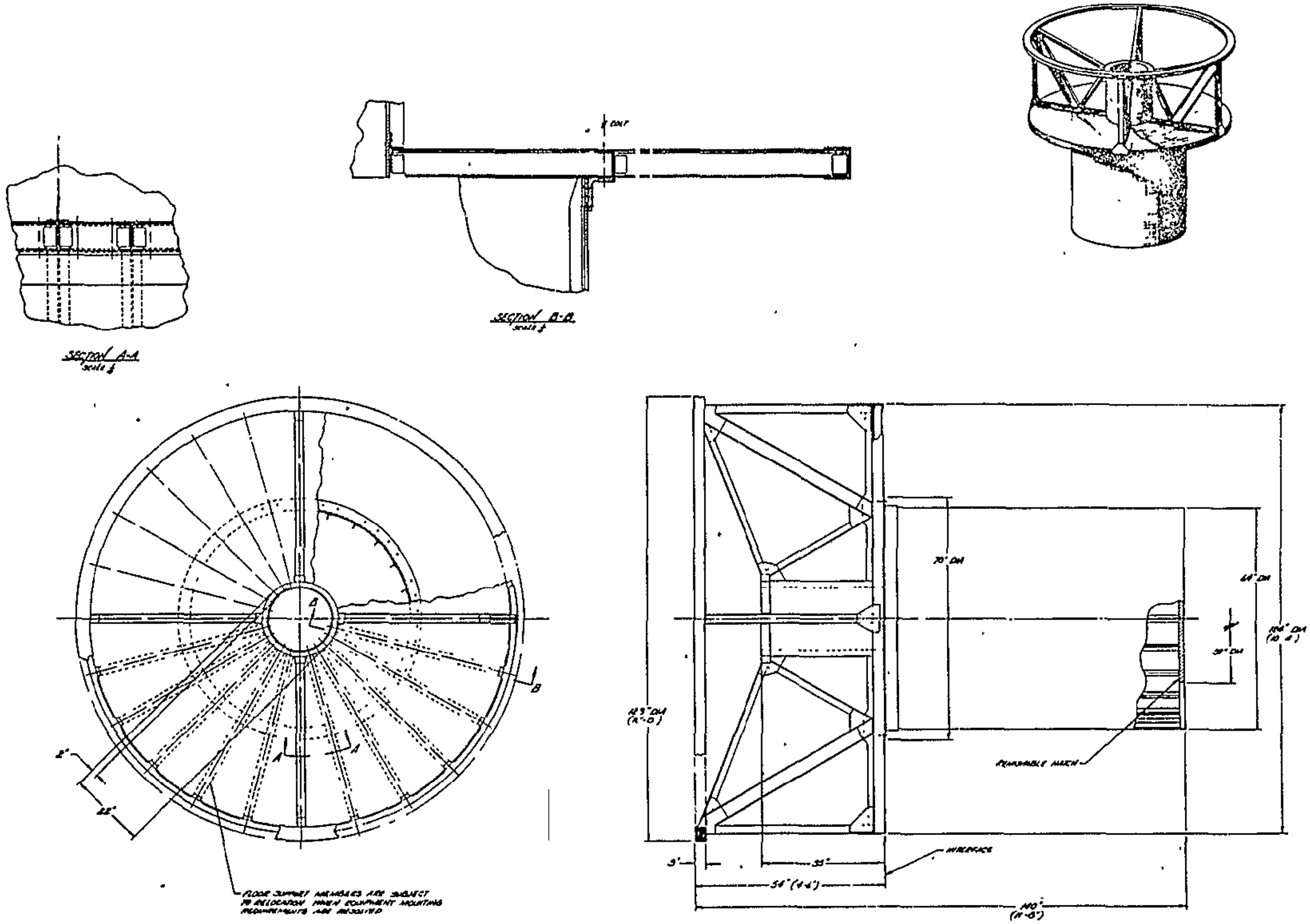


Figure 2-6. Instrument Compartment Cruciform Space Truss

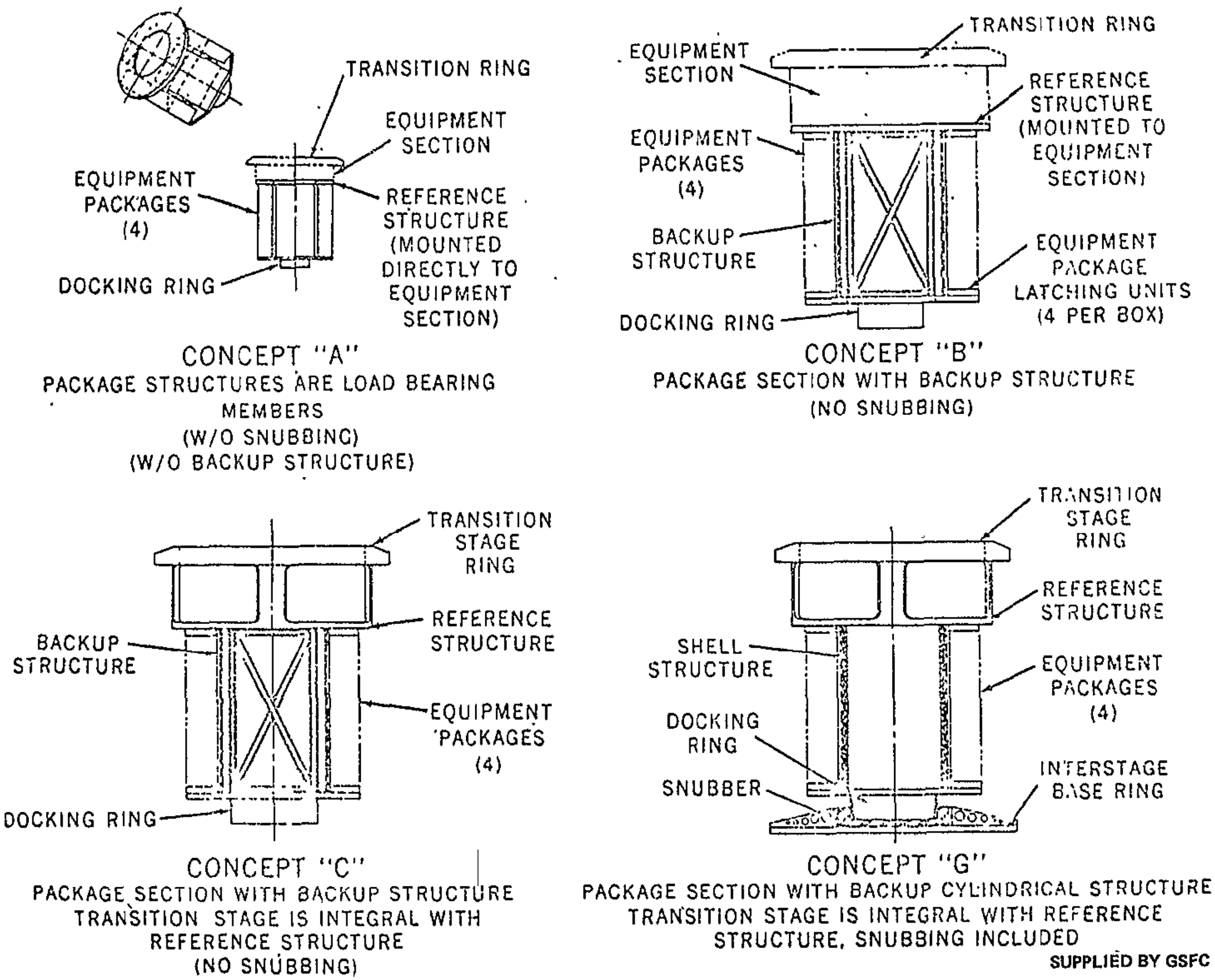


Figure 2-7. Spacecraft and Transition Ring Structure

The transition ring is essentially a circular hollow box beam, of titanium, fabricated as a weldment of hollow forgings. Its OD is 142 in., height is 12 in., and wall thickness 1/2 in. Its radial width is 7 in., i.e. 128 in. ID, with a step down in height at 3 in., inward from the OD. The weldment will have precision machined alignment surfaces. The weight of the ring is 1000 lbs.

The "reference structure" (Figure 2-7) comprises four vertical elements or struts and a horizontal plate. The struts are 1/8 inch titanium sheets as outer sandwich skins, separated with titanium Z-bar reinforcing rods, forming a 3 inch thick sandwich section. The OD of the four struts is 108 inches; total height of the reference structure is 54 inches. Gusset plates are provided at top and bottom of the struts for attachment to the transition ring and the bottom plate.

The bottom plate, 108" OD, is a sandwich panel of titanium, four inches thick, with radial and diagonal stiffening channel elements.

The "shell structure" (Figure 2-7) is an aluminum semi-monocoque design with internal longerons and circumferential stiffening rings extending to one inch radial thickness. The shell is 7-1/2 feet long and 54 inches OD. Four circumferential heat pipes are located on the outer skin, suitably spaced. The base plate is an aluminum sandwich structure similar to that of the reference structure base plate. Precision machined titanium rails are provided radially on the shell structure to receive the subsystem modules. The docking mechanism is attached at the underside of the shell base plate. Weight of reference and shell structures is 1000 lbs., giving a combined weight of 2000 lbs. for the spacecraft and transition ring structure, without the docking mechanism.

The four subsystem module structures are aluminum truss frames 90 inches long, four feet wide and 18 inches deep. Each weighs 250 lbs, and will carry a latching mechanism for final positioning during replacement.

In the case of the Titan launched LST structure the rails of the spacecraft structure and the latching mechanism of the module structures are eliminated. Permanent fastening of the modules is used instead, which is reflected in lower cost for the Titan version.

2.2.1.6 Interstage Adapter for Titan Launch

This structure is of aluminum semi-monocoque construction, with 1/8" thick skin and 1/8" high channel corrugations attached to outside surface for stiffening. The homogeneous, continuous cylinder is 110" in diameter and 14-1/2 ft. long, including a 1-1/2 ft. length for a snubber.

The weight of the interstage adapter is 1000 lb. It is removed from the LST in deployment, by backing the orbit insertion stage away from the spacecraft.

Interface with the shuttle is combined with the remote manipulator as part of the service module described separately in this report.

2.2.1.7 Structural Weight Summary of the LST

ITEM	WT. STRUCTURE	WT. CONTENT
Thermal Shield	1100 lb.	
- Piping -200		900
- Sunshade -300		
- Solar Paddle -250		
- Thermal Blanket -150		
Secondary Mirror Support Structure	2400	
- Secondary Mirror and Mechanism		600
Primary Mirror Support Structure	2300	
- Mirror Support Mech.		400
Primary Mirror		5000
Radial and On-Axis Instrument Structure	1300	
- Offset Tracker Mirror -200		2400
- Offset Tracker and Telescope Electronics -300*		
- Radial Instrument Pkges -900**		
- On-Axis Instrument Pkge -1000***		
Spacecraft and Transition Ring Structure	2000	
- Subsystem Module Structures (Each 250 lb.)	1000	
- Pneumatics Module		400
Comm. and Data		
- Handling Module		400
- Power Module		550
- Stabilization and Control Module		1200
- Smaller Details, Mechanical		400
- Docking Mechanism		(100)
- Titan Interstage	(1000)	
Total	10,100 Structure	12,250 Content

Total LST without docking mech. and interstage 22,350 lb.

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* Includes (1) 100 lb. titanium radial box
** Includes (3) 100 lb. titanium radial boxes
*** Includes (1) 200 lb. titanium axial box

2.2.2 Description of Experiments

The experiment subsystem comprises three of the four radial packages and an on-axis package. The Offset Tracker, which is functionally part of the Stabilization and Control system, is located in the fourth radial package.

2.2.2.1 On-Axis Experiments

The on-axis experiment package is cylindrical, approximately 54 inches in diameter by 86 inches long. It is considered a "mission success" package. This package will contain several internal experiments with an optical switching mechanism that will enable each to use the available light in a sequential manner.

Weight of the on-axis experiment is 800 pounds, exclusive of the container which adds 200 pounds. The three experiments contained in it are (1) an echelle spectrograph, (2) a high resolution imaging (slitless) spectrograph, and (3) a low resolution, wider spectral range, imaging spectrograph.

The on-axis experiment package is the most complex and expensive of the four, making use of the incoming light with a minimum of internal reflections.

2.2.2.2 Radial Experiment Packages

The radial experiment packages will be built by the various principal investigators. The box for each experiment will be supplied to the experimenter to fill with his apparatus. In this way there will be assurance of uniform fit and replaceability relative to the spacecraft structure.

The radial experiments will be simple, compared to the on-axis experiments. Total weight of all three radial experiments is 900 lb. They occupy quarters of a 100 inch OD by 36 inch ID annulus, and taper in height from 42 inches in front to 32 inches in the rear.

The three radial experiments are:

- An imaging field camera,
- A photometer/polarimeter, and
- A Fourier IR interferometer combined with a conventional grating spectrograph.

2.2.2.3 Offset Tracker

The offset tracker utilizes a large diagonal flat mirror, stationary and outside the package, to fold the guidance field through 90°. The mirror has a central hole to pass the experiment field on to the experiment packages.

Two fine error sensors will be provided in the offset tracker, one redundant, capable of rho, theta translation over the 16 inch diameter guidance field. These sensors will be of the image dissector type, and will be physically scanned over the equivalent of 1 minute of arc.

Weight of the offset tracker is 300 lb; and the diagonal mirror, 200 lb.

2.2.3 Spacecraft Mechanisms

2.2.3.1 Primary Mirror Support Mechanism

This mechanism is intended for precise structural support of the primary in its cell, in such a way as to preserve the optical figure of the mirror. It is described, together with the primary mirror, in Reference (1).

2.2.3.2 Secondary Mirror Adjustment Mechanism

This mechanism carries the secondary mirror cell, and is supported on the spider vanes at the far end of the secondary mirror support structure. The mechanism is capable of moving the secondary mirror over a limited range, in five degrees of freedom. It provides a means of compensation for misalignments of the secondary relative to the primary mirror, caused by structural distortion arising from launch stresses or thermal gradients. The mechanism will operate in a closed loop, with signals from a focus and image sensor carried in the on-axis experiment package. Overriding manual control of the mechanism from the ground is also possible.

2.2.3.3 Radial Experiment Selector

This is a mission success mechanism located behind the offset tracker flat, into the central experiment optical path to divert the light to the radial experiments. The mirror is capable of rotation, in order to switch the light to a selected experiment. However, when on-axis experimentation is to be resumed, the mirror must be retracted from the central optical path. If the mechanism fails to do this the on-axis experiment is disabled.

The mechanism is attached to the on-axis package, and therefore replaceable with the on-axis experiment.

2.2.3.4 Structural Spacecraft Mechanisms

These comprise the mechanisms for sun shade deployment, solar paddle deployment and rotation, and latching of the subsystems and experiment modules in place after placement in orbit. They are considered part of the spacecraft structure and are costed with it.

The docking ring, attached to the spacecraft structure in the shuttle supported version, is a stationary unit. The active mechanism for docking is a part of the Shuttle Service Module.

2.2.4 Optics

The 120 inch primary mirror is a monolithic "light-weighted" (cored) structure of low expansion material. The secondary mirror is of similar construction. The offset tracker folding flat is solid and of low expansion material.

The primary mirror is further described and discussed, particularly regarding support means, in pp. 38-45 of Reference (1).

The primary optics are very long lead time items, especially the primary mirror. Thus to protect the program schedule, one more set of optics will be manufactured than the number of vehicles. In this way a failure of the prototype optics in manufacture or transport, for example, would be covered by the available back-up set. If not used for the prototype, the back-up would be available to cover a failure in the optics of a succeeding vehicle.

2.2.5 Spacecraft Subsystems

2.2.5.1 General

The baseline concept for the LST, calls for the nine replaceable modules described previously. The subsystem modules will be available as spares for replacement as complete units, via shuttle service flights, in the event of failure of a critical component or loss of a mission-success function in a subsystem. The experiment modules will be replaced on a regular basis to provide updating and extension of the scientific mission. Each module will require a structural, mechanical, thermal, and electrical interface with the LST and the intent of the design is to keep these interfaces as simple and reliable as possible. Each module will be provided with test connectors for ground test and maintenance as a complete assembly.

2.2.5.2 Stabilization and Control

The detailed listing of S & C components is given in Table 2-3, together with explanatory remarks. Figure 2-8, a & b, shows a functional block diagram of the S & C subsystem. It

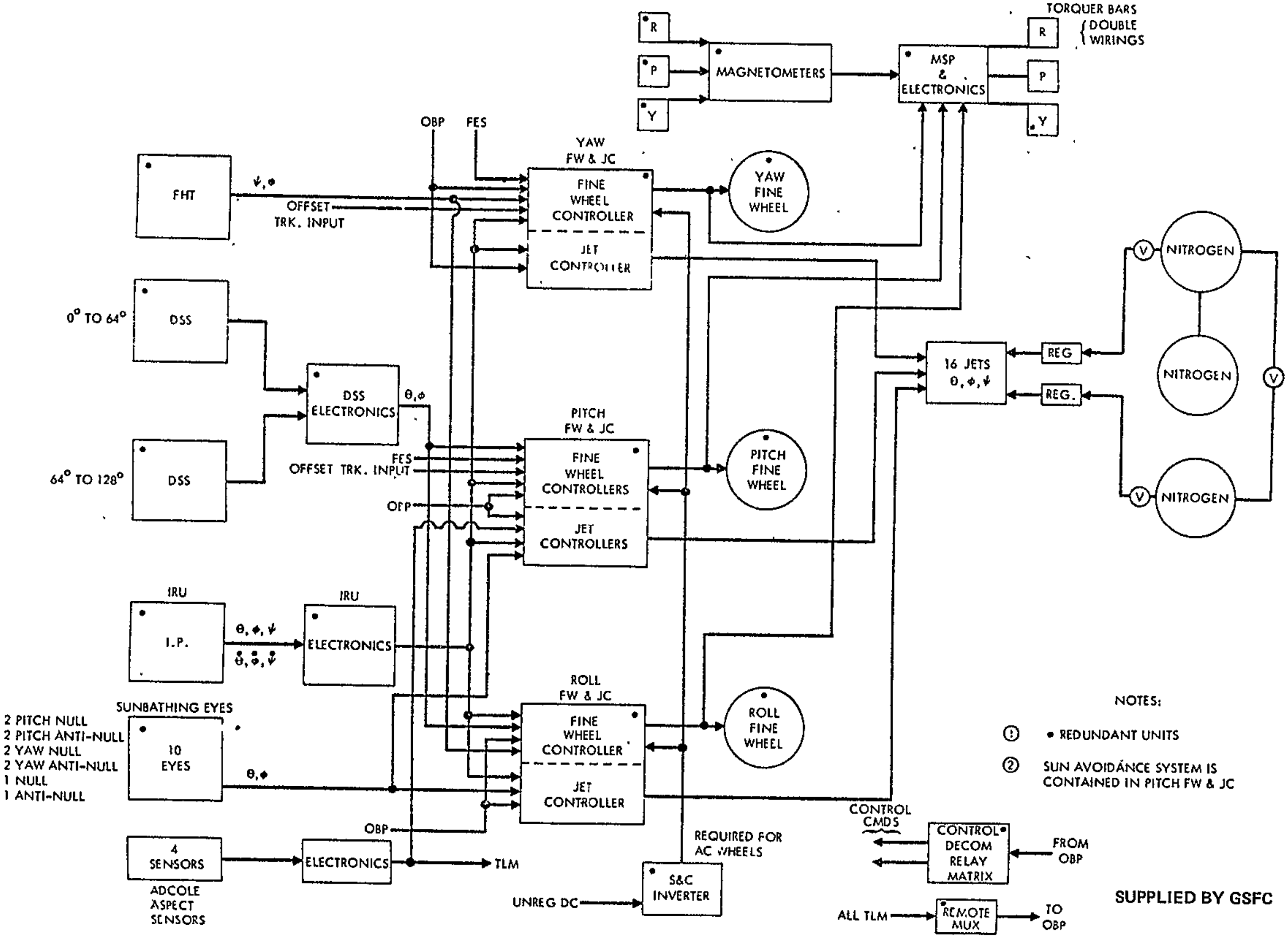


Figure 2-8 (a). Stabilization and Control

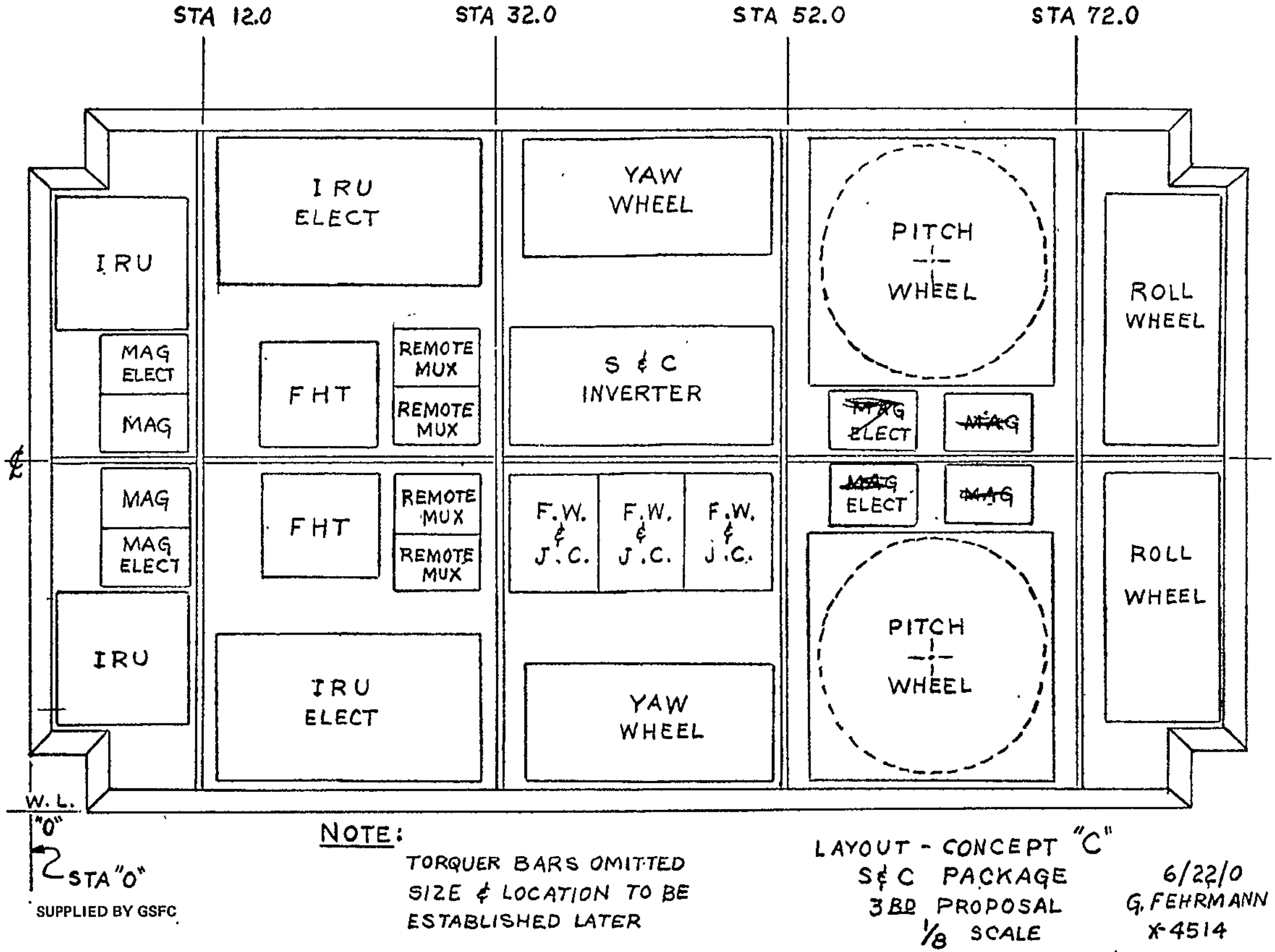


Figure 2-8 (b). Layout - Concept

should be noted that the pneumatics (stored gas) section is located in a separate module as is the offset tracker, which is located in a radial bay module. In addition, three magnetic torquer bars and 16 gas jet nozzles are located elsewhere on the structure and are not replaceable.

The expendable (Nitrogen) gas used for initial stabilization consists of 315# of N_2 stored in three tanks. Under nominal operating conditions, this supply should last for three years or more as extrapolated from present experience with OAO A-2.

The mode sequence of the S & C subsystem progresses from initial spacecraft stabilization to experiment fine pointing utilizing the offset tracker. In the event of failure of a critical S & C component, alternate paths can provide a safe orbital hold and docking stabilization mode.

2.2.5.3 Electrical Power

The detailed listing of Electrical Power components is given in Table 2-3, together with explanatory remarks. The EPS will supply raw D. C. to the other subsystems and experiment modules where conversion and regulation will be performed by standardized sub-modules which are part of each integrated package.

The LST/Shuttle interface will be capable of supplying electrical power during launch and insertion as well as resupply via an umbilical connection to the spacecraft wiring harness. Figure 2-9 is a schematic of the spacecraft harness configuration.

2.2.5.4 Communications and Data Handling

A component listing is given in Table 2-3, together with explanatory remarks.

2.2.5.5 Pneumatics

A component listing is given in Table 2-3, together with explanatory remarks. The 16 gas jets are external to the pneumatics module and are not replaceable (but are multiply redundant). It is presently intended that low pressure regulated gas will be distributed to these jets via pneumatics lines equipped with quick-disconnect couplings between the pneumatics module and the spacecraft lines.

Table 2-3. OAO/LST Subsystem Components, Development Status & Characteristics

STATUS CATEGORIES
1 - Available
2 - Avail. with mods
3 - State of the Art
4 - Development

Subsystem	Component	Status Estimate 7/21	Justification of Estimate	No. Reqd	WT. (lb)	Power (watts)	Size (inches)	Remarks
Communications and Data Handling	Diplexer	2		2	3		6 x 3 x 3	
	Command RCVR	2		4	2		4 x 5 x 4	
	Narrow Band Xmitter	2		1	1.5		6 x 3 x 2	
	Comm. Decoder	2		2	8		8 x 6 x 4	Used with MUX for Inter-Subsystem Comm.
	Telem Format Contr.	2						Used with MUX for Inter-Subsystem Comm.
	On Board Processor: I/O's	2		3	15		8 x 6 x 6	
	Core (RAM)	2	is a "SEMS" 5-L System	16	6		5 x 7 x 4	Random Access Mem. (4K words each x 18 bits)Core
	Bulk Mem.	2		2	10		8 x 6 x 5	1 x 10^6 Bits each - Serial Mem Storage
	C. P. U.	2		3	13		8 x 6 x 6	
	Comp. Oper. Monitor	2		1	2		6 x 6 x 3	
	Narrow Band Tape Rec.	1	Similar to OAO-OGO T-R	1	18		8 x 8 x 6	
	Wide Band Tape Rec.	4	New Dev.	2	18		8 x 8 x 6	
	Wide Band X'mitter	2	Prob. Existing Design	2	2.5		6 x 5 x 2	"S" Band
	Comm. Detector/Verifier	2		2	1.5		4 x 5 x 3.5	Also known as signal combiner, detector (2 req'd)
	Power Amp. & RF Switch							
	Wiring Harness							
	Multiplexer	2		2	10		6 x 6 x 3	
	Power Converter	2		3	7		8 x 10 x 3	
	Tape Rec. Interface	2		1	6		8 x 6 x 3	Like GFEI (on OAO)
Stabilization and Control	Fixed Head Tracker	1	Similar to OAO	2	14	10	12 x 8 x 7	Complete Optics & Electronics in Integrated Package
	Dig. Sun Sens. Elect.	1		1	10		8 x 6 x 4	Electronics only
	Inertial Ref. Unit	1		2	50		9 x 9 x 9	Gyro Package only
	Solar Aspect Sensor	1		1	10		8 x 6 x 4	Electronics only
	FWJC (Controller)	2		3	20		9 x 8 x 6.6	
	Magnetometer	2		2	7		10 x 6 x 4	Sensor only
	Wheels	3		6	60		17 O.D. x 8 deep	
	Inverter	2		1	40		20 x 9.6 x 9	Includes S & C Power Conversion
	Digital Sun Sensor	1		4	2		3 x 3 x 2	Optics only
	Remote Decoder	2		2	15		10 x 6 x 4	
	Multiplexer	2		4	10		14 x 6 x 4	
	Mag. Torquer Bars	3		3	112		6.0" OD. x 45.6" long	OAO torquer Bar Type
	Wiring Harness			1	75			
	IRU Electronics			2	40		18 x 10 x 6	
	Offset Tracker	4		1				Located in Separate Radial Bay Module
	Magnetometer Elect			2	10		10 x 6 x 4	
	Solar Aspect Sens	1		4	2			Optics only

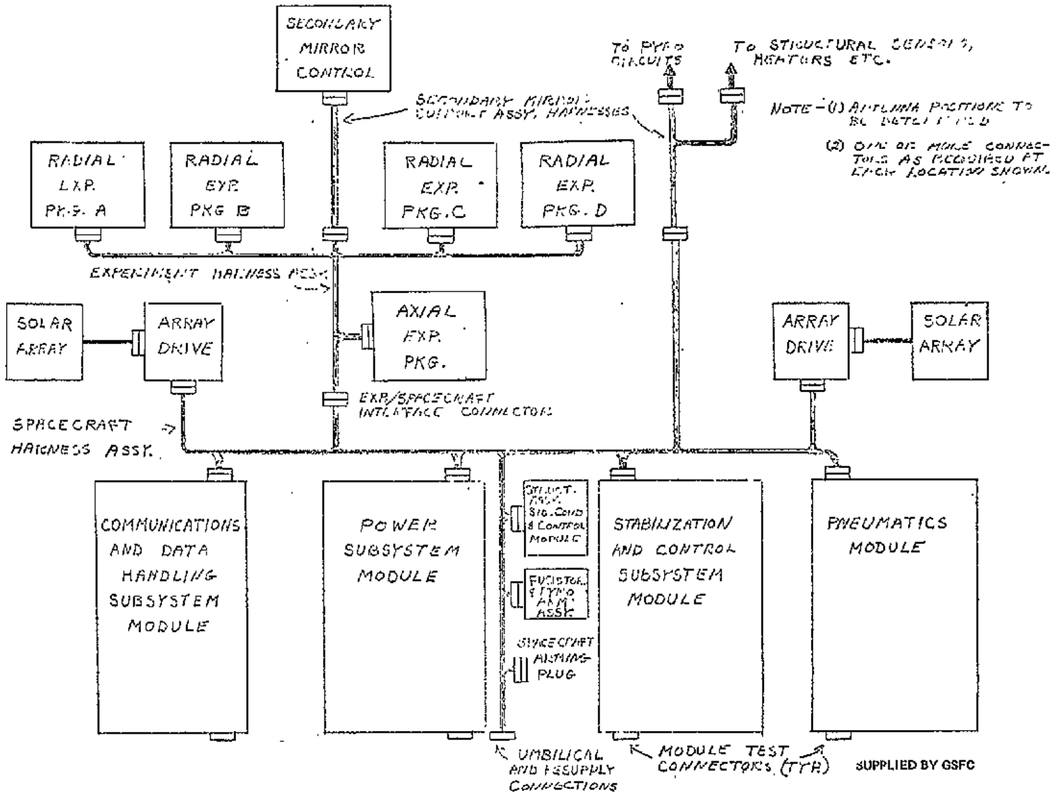


Figure 2-9. Harness Configuration

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 2-3. OAO/LST Subsystem Components Development Status & Characteristics (Cont.)

STATUS CATEGORIES
1 - Available
2 - Avail. with mods
3 - State of the Art
4 - Development

Subsystem	Component	Status Estimate 7/21	Justification of Estimate	No. Reqd	WT. (lb)	Power (watts)	Size (inches)	Remarks
Pneumatics	Gas Tanks	2		3				315# N_2 Total Gas Wt.
	Regulators	2	Like OAO	2				Hi-Pressure
	Solenoid Valves	2		16				Coaxial Solenoid Valves - Hi thrust (located in S & C Module)
	Valves (Shut-off)	2		3				Latching
	Piping	2						Flexible Tubing from PN-Module to Jets
	Wiring Harness							
	Gas Jets (Hi-thrust)	1		16				Not in Subsyst. Module - Mounted on S/C struct.
	Pneu. Connectors	3						
	Fill & Dump Syst.							
Electrical Power	Batteries	1	Similar to OAO	6				20 A-H (22 cell Ni-Cad.) Anhydrode cell in each
	Battery Chg. Contr.	3		12				PWM Reg.
	Solar Array	1					≈ 240 ft.^{2}	10Ω-cm cell, 57,536 N-P Silicon, 2 x 2 cm. x 14 mil thick
	Multiplexer	2			10			
	Diode Box	2						
	Power Dist. Unit.	2						
Structure	Thermal Shield	2	Modified Titan Tank	1	1100			Aluminum
	Sec. Mirror Support	4		1	2400			Titanium Trusswork
	Prim. Mirror Support	4		1	2300			Titanium
	Instrum. Support	4		1	1300			Titanium
	Subsyst. Support	3		1	2000			Spacecraft (Aluminum) & Transition Ring (Titanium) Ass'y
	Docking Ring	3	GAC-Evolved Design Concept	1				
	Solar Arrays	2	Like OAO	2	125			As per OAO Design
	Sunshade	2		1	300			Aluminum
	Subsyst. Mod. Struct.	3		4	250			Aluminum
	Radial Mod. Box Struct.	3		4	100			Titanium
Primary Optics	Primary Mirror	4	GSFC Data	1	5000			Optically Polished Cervit (Owens-Illinois)
	Secondary Mirror	4		1	500			Optically Polished Cervit
	Optical Align Assy's.							
	Offset Tracker Folding Flat			1	250			Optically Polished Cervit.
Spacecraft Mechanism	Solar Array Drive	3	Bendix Data	2	50			Wt - Estimate
	Sunshade Development	3		2				
	Docking Mech.	4		1				
	S/S Latching Mech's	3		9				Part of Replaceable Module Struct. Assy's
	Prim Mirror Support	4		33				
	Sec. Mirror Adjust Mech.	4	GSFC Data	1	100			

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 2-3. OAO/LST Subsystem Components Development Status & Characteristics (Cont.)

STATUS CATEGORIES
1 - Available
2 - Avail. with mods
3 - State of the Art
4 - Development

Subsystem	Component	Status Estimate 7/21	Justification of Estimate	No. Reqd	WT. (lb)	Power (watts)	Size (inches)	Remarks
Thermal	Heat Pipes Skins Louvers Heaters Thermal Blankets	2 2 2 1 1	OAO - B Experiment OAO - B Experiment Like OAO A-2, B, C Like OAO	 4	250 150			Approx. lbs., Distrib. About S/C Silver-teflon Tape (GSFC Devel.) Located on Subsyst. Module Struct. Distrib. about S/C
Elect. & Wiring	S/C Harness Struct. Instrum. Fusistor & Pyro Struct. Heaters Antennas - S, Band - VHF	3 1 2 1 2		1 2 2				
Service Module	Docking Mech Servicing Mech. Module Storage Mech	4 4 4	New Devel.	1 2 2				GSFC Layouts
Strongback Mech.	Strong Back Erection Mech.	4 4	New Devel.	1 1				GSFC Layouts
LST/Shuttle Flight Support	LST "Soft Mount" Cradle Shuttle hard point Pickup Mech.	4 3		1 1				
LST/TITAN flight support	LST/Titan Interstage Bulbous Shroud	3 2	 NASA Program	1 1	1000			 NASA Development "Viking" shroud Program
Scientific Exper.	On-Axis Exper. Module Radial Exper. #1 Radial Exper. #2 Radial Exper. #3	4 4 4 4	GSFC Data	1 1 1 1	1000 300 300 300		54" OD x 86" lng. Pie Shaped Pie Shaped Pie Shaped	"Mission Success" Exper. - 2 yr. Replacement Low Cost Exper. - 1 yr. Replacement GAC to Cost Module Struct. Low Cost Exper. - 1 yr. Replacement GAC to Cost Module Struct. Low Cost Exper. - 1 yr. Replacement GAC to Cost Module Struct.

2.3 MANUFACTURING

The major manufacturing effort is directed towards fabrication of six (6) flight LST structures to be launched by conventional means. The first LST structure will be utilized as a structural test article (STA) and later refurbished to a flight article. Additionally, a wood/metal mockup of the spacecraft section will be utilized for development of electrical and fluids lines runs, and a systems test stand (STS) to test and checkout spacecraft sub-systems and experiment modules.

2.3.1 Manufacturing Schedule

A tentative LST Manufacturing Schedule is shown in Fig. 2-10. The schedule summarizes the manufacturing activities necessary to meet program milestones.

The fabrication of the STA and the flight articles is spread over seven years to minimize yearly manpower and tooling requirements while maintaining shop efficiency. The first fabrication bar for flight articles 2 through 5 represents the effort necessary to complete the structure. The structures will then be placed in storage until 19 months prior to launch. Three of these months will be utilized to update the structure and install and checkout the electrical and pneumatic lines. The remainder of the time is for installation of equipment, test and checkout.

The Contractors philosophy in manufacturing of the LST will utilize streamlined prototype shop operations in a centralized facility. This will be based heavily on previous OAO experience. A nucleus of versatile, highly skilled and flexible shop personnel will be utilized, and a minimum of formal tooling is anticipated. The centralized facility will reduce lines of communication, reduce paperwork and make possible simplified drawings and methods sheets. Handling time and costs will also be reduced by the central location, and generalized tool shop equipment will be emphasized for fast turnaround. In general, such an approach to manufacturing is ideally suited to low quantity, highly engineered hardware programs such as the LST.

2.3.2 Flight Vehicle

The LST flight articles consist of five major subassemblies (Figs. 2-2, and 2-3). These are the spacecraft and transition ring, the radial and on-axis instrument structure, the primary mirror support, the secondary mirror support and the thermal shield. In addition, there are four subsystem modules, four radial experiment modules, an on-axis experiment

FOLDOUT FRAME 1

FOLDOUT FRAME 2

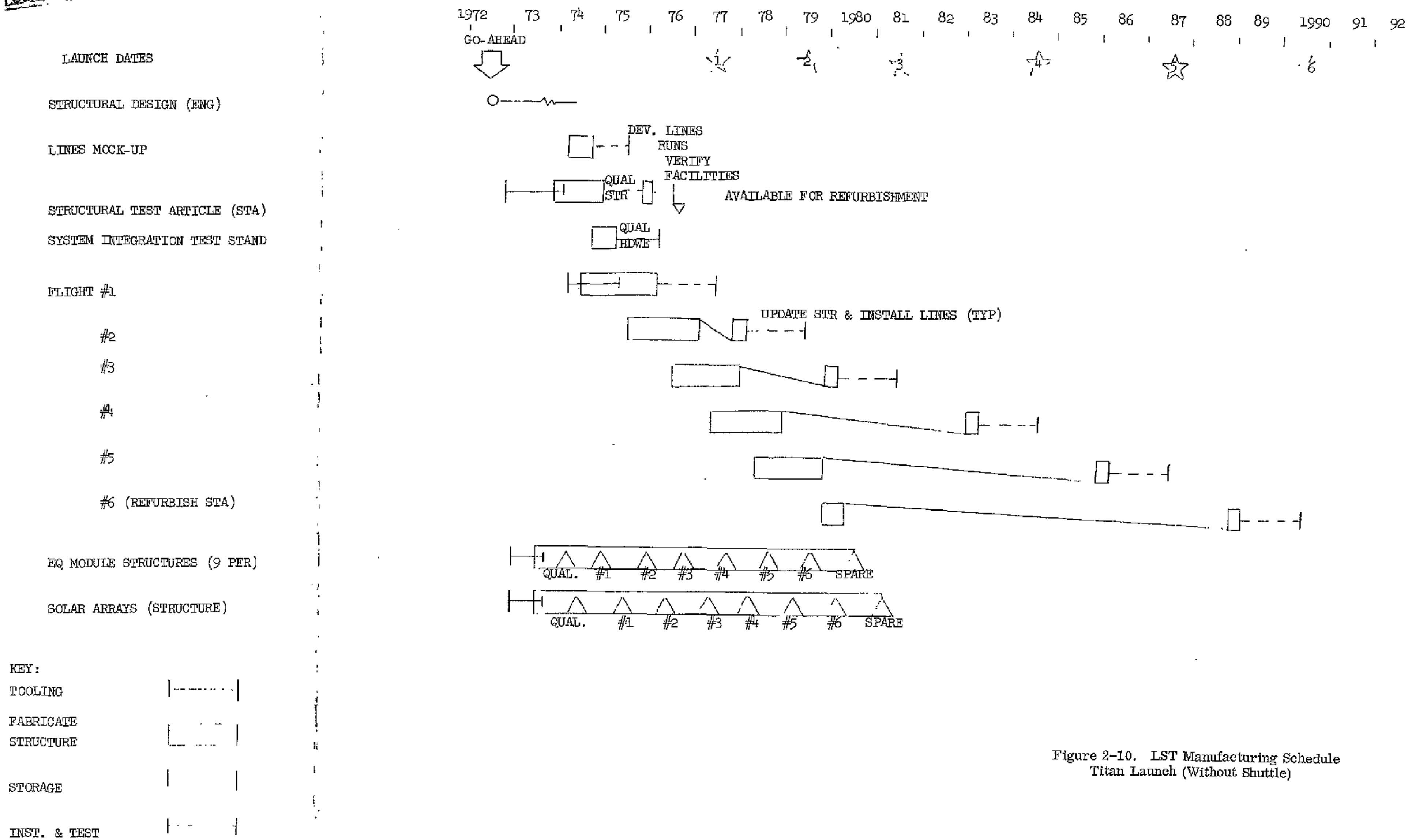


Figure 2-10. LST Manufacturing Schedule Titan Launch (Without Shuttle)

module, a light shield, interstage and two solar arrays. A high percentage (approximately 80%) of the structure is fabricated from welded titanium. The module structures will be fabricated in-house. These structures will then be shipped to the subsystem manufacturers and experimenters for equipment integration and testing prior to return for spacecraft installation. Six flight vehicles will be manufactured. The first is considered a prototype but the structure will be identical to the subsequent articles. The STA will be refurbished into the sixth flight vehicle.

2.3.2.1 Flight Vehicle Buildup

Flight vehicle buildup consists of the manufacture and assembly of the structure, installation of electrical and pneumatic lines, mirrors and equipment modules and alignment and testing of spacecraft systems.

2.3.2.2 Major Subassemblies

Most of the major subassemblies will be fabricated from titanium sheet, tubing, plate and machined parts using the manual TIG welding joining methods. The process produces good weld joints in the gages required by the design and the resulting assembly has better thermal properties than a mechanically fastened structure. Combination assembly and weld fixtures will be utilized to limit tooling cost.

The secondary mirror support structure fabrication procedure is an example of the cost savings manufacturing planning that was done for vehicle buildup. This support assembly consists of a six bay circular titanium truss structure, 129 inches in diameter and 30 feet long. (Figure 2-4). The circumferential rings will be fabricated by forming tubular arc segments and butt welding them together. Rather than build a large assembly weld fixture to hold all six bays, a tool will be designed to weld the trusses one bay at a time. As each bay is welded, it will be indexed so the next bay can be welded to it. The required accuracies will be maintained by the indexing procedure.

2.3.2.3 Final Assembly

The spacecraft transition and telescope sections will be assembled concurrently. The final assembly phase will include joining of the two major assemblies, spacecraft and telescope, the installation of lines and prefit of the solar arrays and interstage to the spacecraft.

Assembly of the spacecraft is completed by joining the spacecraft subsystem support with the transition ring.

Assembly of the telescope requires the joining of the primary and secondary mirror support structures, the radial and on-axis instrument support structure and the thermal shield. Prefit to the transition ring and initial alignment will be accomplished at this time.

During the assembly of the telescope, critical equipment and instrument interfaces will be established on the supporting structures. This will be accomplished with the use of optically aligned installation fixtures. A network of optical lines of sight will be integrated in the assembly fixture, controlling the orientation of all critical equipment interfaces.

After structural assembly of the spacecraft and telescope, pneumatic and electrical lines will be installed. Linkages and mechanisms will be assembled and initially adjusted.

The telescope assembly will be disassembled and the primary mirror support structure will be shipped to the mirror fabricator for installation. Upon receipt of the mirror and support structure, the telescope structure will be reassembled, and the secondary mirror and adjustor mechanism installed. The telescope will be joined to the spacecraft structure, completing final assembly.

Tooling required for the spacecraft and telescope subassemblies includes structural and alignment assembly fixtures, equipment and instrument interface installation tools. Optical alignment equipment will be permanently installed in the telescope assembly and alignment fixture.

2.3.2.4 Subsystems Installation and Factory Checkout

Subsequent to structure assembly and lines installation and checkout, the vehicle will be cleaned before subsystems are installed.

Installation and checkout of subsystems modules will be accomplished in serial time to isolate the testing of the systems. When all four system modules have been installed and are functioning properly, the offset tracker and the experiment modules will be installed and their operation verified. Finally, the entire vehicle will be functionally integrated and operated. Following this test, it will be weighed and its center of gravity determined prior to packing and shipment to GSFC.

2.3.2.5 Mockup

A wood and sheet metal mockup of the spacecraft section will be fabricated for use in development of the electrical and pneumatic lines runs and harness configurations between subsystem modules and experiment modules and thrusters, etc.. Methods engineers will support design engineering in determining the optimum lines routing.

2.3.2.6 Structural Test Article

The structural test article (STA) structure will be identical to the flight vehicle structures. It will not contain equipment or electrical/pneumatic lines. Mass representations will be installed to simulate the equipment modules and mirrors. Thermal insulation blankets will not be installed. Heat pipes will be functional. Strain gages and accelometers will be installed, test fixtures assembled and set up and test support provided.

Subsequent to static and dynamic testing, the exterior (thermal blankets, etc.) and solar arrays will be simulated and the article will be used for facilities verification and launch vehicle match/mate tests. The structure will then be refurbished for use as a flight vehicle.

2.3.2.7 System Test Stand (STS)

This test stand will provide a means to integrate, test and qualify the subsystems and experiment modules. The structure will be fabricated to locate the various modules in their relative spacecraft positions. Flight configured wire harness and pneumatic lines will be used for interconnections. Provisions will be made for test taps and stimuli.

2.3.2.8 Ground Support Equipment

Ground support equipment will be manufactured to support development test and flight article manufacture, acceptance test, transportation, launch and orbital operations. This equipment will either be of new design or modified from the OAO program.

2.3.2.9 Off-Site Manufacturing Support

Testing at GSFC and pre-launch operations will be supported by manufacturing test technicians as required.

2.3.3 Shuttle Launch

The major manufacturing effort for a Shuttle launch-revisit program is directed towards fabrication of three (3) flight structures. The first structure will be utilized as a structural

test article (STA) and later refurbished to a flight article. A wood/metal mockup of the spacecraft section will be utilized for development of electrical and fluids lines runs, and a systems test stand (STS) to test and checkout spacecraft subsystems and experiment modules.

2.3.3.1 Schedule

The LST Manufacturing Schedule-Shuttle Launch-Revisit is shown in Figure 2-11. The manufacturing activities necessary to meet program milestones are summarized thereon.

The fabrication of the STA and the two flight structures is scheduled to minimize yearly manpower and tooling requirements while maintaining shop efficiency. The second flight structure and refurbishment of the STA will be completed up to the point of lines installation and then placed in storage. Eighteen months prior to launch, the structures will be removed from storage, up-dated and the lines installed in preparation for final equipment installation, test and checkout.

2.3.3.2 Flight Vehicle

The LST flight article structure for the Shuttle program is identical to that required for conventional launch with the addition of a soft docking mechanism, automated equipment module latches and quick-disconnects, and Shuttle cargo bay interface support points. Three flight (3) vehicles and one spare set of replaceable subsystem modules will be fabricated.

2.3.3.3 Flight Vehicle Buildup

The flight vehicle buildup for Shuttle launch and resupply missions is identical to the sequence for the conventional program. Because of the resupply capability of the Shuttle, however, additions must be made to the spacecraft to accommodate the launch/supply mechanism.

A soft docking mechanism must be added to the lower end of the spacecraft and transition ring structure, and Shuttle cargo bay support interface fittings to the transition ring. Remote controlled latches and quick disconnects must be added to the subsystem and experiment module interfaces. To insure 100% interchangeability, master tool gages and inspection checking tools must be provided to coordinate the assembly fixtures.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

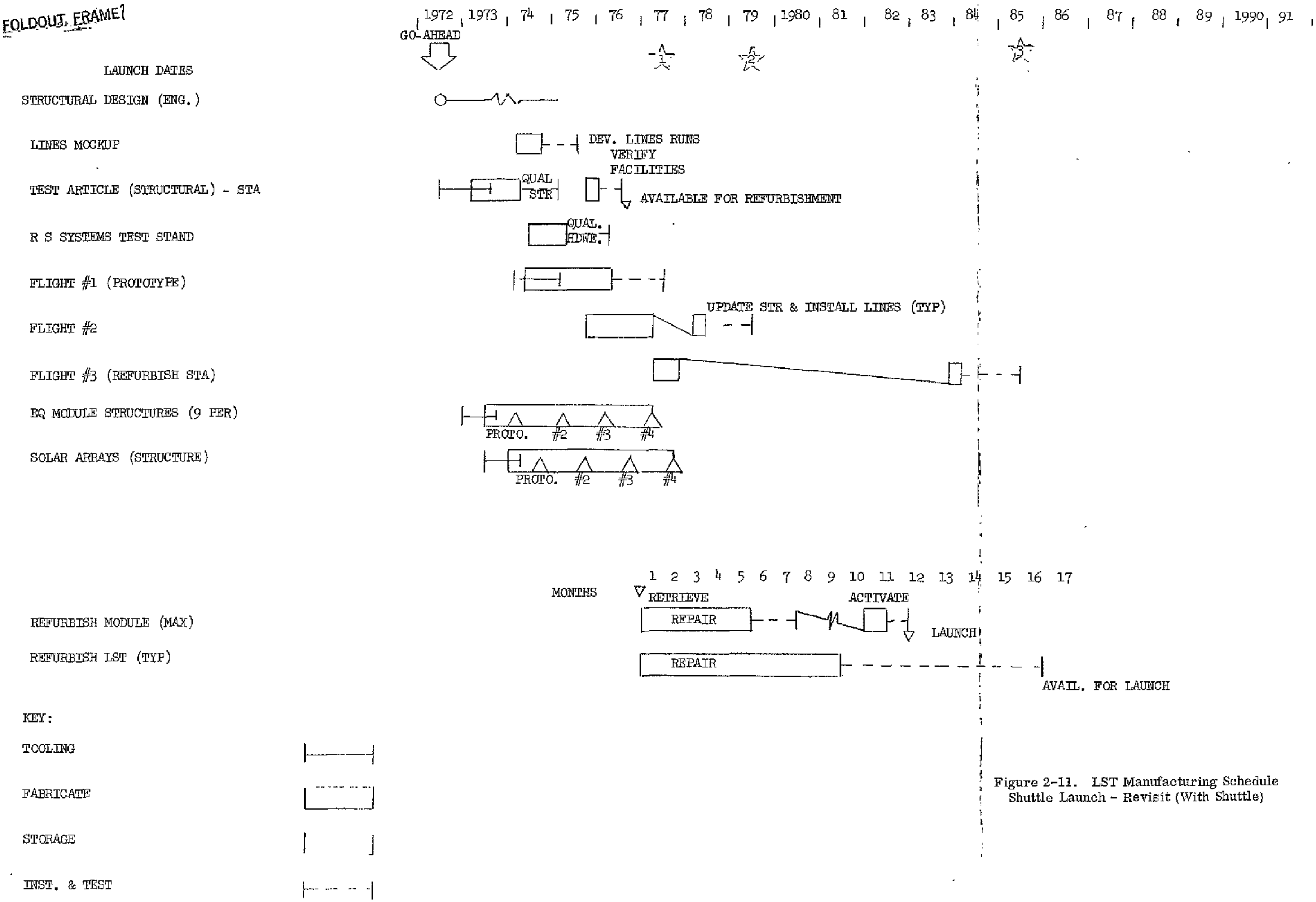


Figure 2-11. LST Manufacturing Schedule Shuttle Launch - Revisit (With Shuttle)

2.3.3.4 Interstage Adapter

One interstage adapter will be required for the first launch since this is to be a conventional launch. Subsequent launches will be via Shuttle.

Final assembly, critical alignments, electrical and pneumatic lines and equipment installations, factory checkout; and off-site manufacturing support are similar to those operations described in Sections 2.3.2.3, 2.3.2.4, and 2.3.2.9 for the Titan baseline LST vehicles.

2.3.3.5 Ground Support Equipment

Ground Support Equipment will include both modified OAO equipment and new design. It will be similar to that required with the Shuttle.

2.3.3.6 Launch-Resupply Mechanism

A special LST cradle/supply module must be fabricated for installation into the Shuttle for each mission. A strong back will be used to cradle the LST in the Shuttle cargo hold during launch and retrieval. It will be capable of changing the nine replaceable modules on the spacecraft.

Both the strong back and the service module will be fabricated from aluminum sheet metal, extrusions and machined fittings. Deployment cylinders, elevator and the docking mechanisms and snubbers will be installed. Tools will be required to maintain the interchangeable mechanical and electrical interfaces.

2.3.4 Manufacturing Cost Estimate

The manufacturing estimate shows comparative costs for a six (6) flight vehicle program to the Titan baseline concept and a three (3) flight vehicle program to the Shuttle baseline concept. The first vehicle in either program is to be a structural test article, refurbished later to flight status.

2.3.4.1 Concept

The Titan/LST concept is based on the launch of six LST's by an existing launch vehicle, namely Titan IIID7.

The Shuttle/LST concept is based on the launch resupply/retrieval of two (2) LST's by a new launch vehicle namely Shuttle, and one (1) launched by Titan (because Shuttle unavailable) with the same resupply/retrieve features as the two (2) Shuttle launched vehicles.

Six (6) Titan interstages are required for the Titan/LST launch program. One (1) Titan interstage is required for the first launch (by Titan) of the Shuttle/LST program.

Modification of the Shuttle to accept the LST has not been included in this estimate but is included in the total program as shuttle modification costs.

One (1) additional set of subsystem/experiment modules, has been included in the SHUTTLE/LST estimate. Additional sets were not included for Titan/LST.

Spares of a more general nature have not been included in either program cost because of storage problems arising from a lengthy program and the possibility of cannibalizing later vehicles until program experience indicates a trend and need for spares items.

Basic differences between Titan/LST and Shuttle LST concept occur in the launch vehicle mounting areas and between the fixed subsystem and experiment modules for Titan LST versus the replaceable subsystem and experiment modules for Shuttle LST. The following shows the differences:

	Titan LST	Shuttle LST
Telescope	Same	Same
Spacecraft	Same	Mechanical and electrical modifications for module replaceability
Transition Ring	Same	Same
Interstage	Titan Interstage	Shuttle Strongback* Provisions
Sub-System Modules	Not repairable or retrievable in orbit	Repairable, retrievable in orbit
Experiment Module	Not repairable or retrievable in orbit	Repairable, retrievable in orbit

2.3.4.2 Conditions and/or Assumptions

The following conditions and/or assumptions are applicable to the manufacturing estimate and are in accord with the ground rules established by Program/Engineering for this study.

*Allowance for one (1) Titan launch interstage was included in Shuttle/LST estimate because of late Shuttle launch availability.

The same conditions/assumptions are applied to either Titan LST or Shuttle LST concept except the quantities will read (6) for Titan and (3) for Shuttle.

- Preliminary design will be completed by GSFC.
- The prime contractor will produce detail drawings from the GSFC design.
- The prime contractor will perform development testing and manufacture six (6) flight articles (Titan LST) or three (3) Shuttle LST.
- Sub-system/component detail design will be performed by the sub-contractor.
- Development testing and qualification of the sub-systems/components will be performed by the sub-contractor.
- Experiment modules will be supplied GFE.
- The contractor will integrate spacecraft sub-systems/components to the system, but the sub-contractor will be responsible for replacement/repair of defective sub-systems (black boxes).
- Environmental testing will be done at GSFC.
- Vehicles will be manufactured to either the same Titan or Shuttle point design.
- Major design changes and vehicle updating allowances have not been included in the estimate.
- The manufacturing estimate does not include support of the vehicle at GSFC or KSC.

2.3.5 Estimating Rationale Titan LST and Shuttle LST

2.3.5.1 Structure

The Manufacturing Planning Estimate was prepared after analysis of OAO and LM structural cost histories and application of the experience derived from the structural build up and test programs for these successful spacecraft. Appropriate materials and fabrication complexity factors for titanium construction were based upon recent experience with titanium airframe structure for the Navy's F-14 and projected manufacturing capability resulting from this ongoing program.

2.3.5.2 Systems Fabrication and Installation

Manufacturing and installation of:

- Wire harnesses
- Fluid Lines
- Pneumatic Lines
- Equipment

etc. were directly related to OAO experience as was test and checkout of the vehicle. A 95% learning curve was used for vehicle recurring cost. The flat curve was considered

applicable because of the lengthy program, low production rate and the long storage periods between structural assembly and final assembly for vehicles #2 through #6.

2.3.5.3 RC 23

The estimate was prepared in conjunction with the Support Engineering Department and was based on OAO experience and Support Department knowledge of currently available support equipment.

2.3.5.4 RC 40/74

The estimate was based on a review of the LST design tooling hours required for the spacecraft and were directly based on OAO experience with additional hours being estimated for the telescope sections. Hours for RC 40 Methods have been included in the estimate. Sustaining tooling was estimated as 1% per month of non-recurring tooling hours expended for the continuous manufacturing period and as a level of effort for stretched out storage/final assembly period.

2.3.5.5 RC 52

The estimate was based on the relationship of RC 52 hours to RC 20/23. A 15% relationship was used for the program with higher manloading during the continuous manufacturing period and a level of effort during the stretched out storage/final assembly period. The percentage was derived from LM/OAO experience.

2.3.6 Product Manufacturing Cost Summary Total Hours

The following tables summarize the manufacturing estimate for (6) Titan baseline concept LST and (3) Shuttle baseline LST. Total manufacturing delta hours are also shown.

MANUFACTURING HOURS IN THOUSANDS

		Titan Baseline			Shuttle Base		Delta	
	Qty.	N.R.	Recur.	Qty.	N.R.	Recur.	N.R.	Recur.
LST	6	1,535	4,413	3	1,697	2,511	+162	-1,902
Interstage	6	58	304	1	58	66	-0-	- 238
Sets Modules				1	-0-	73	-0-	+ 73
		1,593	4,717		1,755	2,650	+162	-2,067
Totals		6,310			4,405		-1,905	

Total Shuttle concept manufacturing saving 2,067 - 162 = 1,905 hours.

LST ECONOMIC STUDY
MATERIAL

$ in Thousands

Production

	Titan		Shuttle			
	Non Rec.	Rec.	Non Rec.	Rec.	Non Rec.	Rec.
Vehicle	816.0	5539.0	912.0	3165.0	+96.0	-2374.0
Interstage	50.0	277.0	50.0	50.0	-0-	- 227.0
Modules	-0-	-0-	-0-	87.0	-0-	+ 87.0
	866.0	5816.0	962.0	3302.0	+96	-2514.0
Totals	6682.0		4264		-2418.0	

SHUTTLE SAVINGS 2514 - 96 = 2418.0

Tooling

Vehicle	583.0	506.0	648.0	287.0	+65.0	- 219.0
Interstage	30.0	22.0	30.0	12.0	-0-	- 10.0
Modules	-0-	-0-	-0-	-0-	-0-	-0-
	613	528.0	678.0	299.0	+65.0	- 229.0
Totals	1141.0		977.0		- 164.0	

SHUTTLE SAVINGS 229.0 - 65.0 = -164.0

The following tables show the manufacturing estimate by non-recurring/recurring and by Resource Code for (6) Titan LST baseline concept and (3) Shuttle LST baseline concept.

	(6) LST Titan Baseline Non Recurring	(6) LST Titan Baseline Recurring	(3) LST Shuttle Baseline Non Recurring	(3) LST Shuttle Baseline Recurring
RC 20	730,000	3,329,000	799,000	1,901,000
RC 40	280,000	170,000	308,000	90,000
RC 74	300,000	300,000	330,000	150,000
RC 23	100,000	100,000	120,000	70,000
RC 52	125,000	514,000	140,000	300,000
TOTALS	1,535,000	4,413,000	1,697,000	2,511,000
TOTALS NON REC. & REC.	5,948,000		4,208,000	

	(6) Titan Interstage		(1) Titan Interstage	
RC 20	20,000	240,000	20,000	43,000
RC 40	12,000	6,000	12,000	3,000
RC 74	18,000	18,000	18,000	9,000
RC 23	4,000	4,000	4,000	4,000
RC 52	4,000	36,000	4,000	7,000
TOTALS	58,000	304,000	58,000	66,000
TOTALS NON REC. & REC.	362,000		124,000	

			(1) Set Modules	
RC 20			-0-	63,000
RC 52			-0-	10,000
TOTALS			-0-	73,000
TOTALS NON REC. & REC.			73,000	
TOTALS	6,310,000		4,405,000	

The following table shows the manufacturing estimate for (6) Titan LST baseline concept and (3) Shuttle LST baseline concept.

RC 20 Manufacturing	(6) LST Titan Baseline	(3) LST Shuttle Baseline
Recurring		
Major Structure	2,100,000	1,100,000
Sub-Systems Fabrication & Assembly	648,000	445,000
Final Assembly, Checkout & Test	581,000	356,000
Total RC 20 Recurring	3,329,000	1,901,000
Non-Recurring Hours		
Mock-up	40,000	50,000
STS	40,000	50,000
Development	200,000	220,000
Refurbish STA	450,000	479,000
Total Non-Recurring Hours	730,000	799,000
Total RC 20 Recurring & Non-Recurring	4,059,000	2,700,000
RC 40/74 Tooling		
Non-Recurring		
Methods	80,000	88,000
Design	200,000	220,000
Build	300,000	330,000
Sub-Total Non-Recurring	580,000	638,000
Recurring	470,000	240,000
Total Tooling Recurring & Non-Recurring	1,050,000	878,000

	(6) LST Titan Baseline	(3) LST Shuttle Baseline
RC 23 Support		
Non-Recurring	100,000	120,000
Recurring	100,000	70,000
Total RC 23 Recurring & Non-Recurring	200,000	190,000
RC 52		
Non-Recurring	125,000	140,000
Recurring	514,000	300,000
Total RC 52	639,000	440,000
TOTAL MANUFACTURING	5,948,000	4,208,000
Non-Recurring	1,535,000	1,697,000
Recurring	4,413,000	2,511,000
TOTALS	5,948,000	4,208,000

MANUFACTURING HOURS #1 SPACECRAFT

This estimate is vehicle only and does not include interstage or spare/resupply module costs.

	LST Titan Baseline	LST Shuttle Baseline
Primary Mirror Support	87,000	87,000
Secondary Mirror Support	93,000	93,000
Thermal Shield	41,000	41,000
Radial and On Axis Inst. Structure	59,000	59,000
Spacecraft	49,000	49,000
Transition	49,000	49,000
Sub-Total:	378,000	378,000
Cooling Pipes	4,000	4,000
Sunshade	17,000	17,000
Solar Paddles	15,000	15,000
Thermal Blankets	6,000	6,000
Experiment Boxes	17,000	29,000
S/S Structure	24,000	41,000
Docking Ring	-0-	9,000
Pneumatics	5,000	5,000
Mechanical Details	16,000	16,000
Spacecraft Wiring	13,000	13,000
Final Assembly, Checkout and Test	105,000	110,000
Total #1:	600,000	643,000

	LST Titan Baseline	LST Shuttle Baseline
Refurbish Station to F.A.		
Refurbish • Systems	222,000	251,000
• Structure	228,000	228,000
Total Refurbish:	450,000	479,000
Mock-up	40,000	50,000
SITS	40,000	50,000
Development	200,000	200,000

Final Assembly, Checkout and Test

Final Assembly	20,000
Component Test	55,000
Vehicle Test	30,000
Total	105,000 hours

2.3.7 Quality Assurance

The latest NASA Quality Document NHB 5300.4 has served as a guideline for a Quality Assurance Plan. The plan follows the intent of the NASA document which is to identify the prime quality program "cost drivers", and minimize them without incurring additional risks, and without sacrificing established high quality standards. Candidate areas have been identified and included in this study. However, GAC and NASA approval for future implementation of the assumptions listed below will be required.

2.3.7.1 Inspection

- Drawings

  General line drawings listing EMC (Electromagnetic Compatibility) groupings and approximate lengths are acceptable in lieu of formal lines drawings.

- Government Inspection Agency NASA/NAVPRO effort for the entire OAO/LST Program is on a customer post audit basis. The NAVPLANTREP Team Verification System permits the GAC Quality/Inspection personnel to move ahead in the manufacturing/test cycle with monitoring and/or surveillance by the GIA. During the "Spotcheck" function by Government Inspectors, any items requiring

corrective action or follow-up are accomplished by approved procedures. All current DOD (Aircraft) Programs for Government acceptance are conducted in this manner. In addition, the delegation of contractor personnel to perform inspection for the Government Inspection Agency is assumed.

- Non-Conformance Procedure

  The large aircraft MDR (Minor Discrepancy Repair) Manual is adapted to satisfy all areas of fabrication. A section on Electrical Connectors will be added to the manual. MDR type repairs for simple items are permitted without the service of Liaison Engineering. The documentation and sign-off shall be accomplished by inspection on the vehicle discrepancy sheet.

  Critical items shall require full processing of the MDR Procedure.

2.3.7.2 Project Quality Engineering at Sellers Facilities

- Quality Engineering participation at Design Reviews is considered mandatory. New technological elements that may require specialized equipment and/or personnel training will then be known early in the program, thus avoiding costly crash "catch up" programs.

  An additional Program Cost Reduction is realized by developing a well defined Parts/Components/Assemblies Manufacturing Flow Chart for each Flight Unit or Module during early program planning at Seller's. Quality/Inspection points with inspection criteria documents clearly indicated will be provided. The final sequence chart will be available for contractor approval by CDR (Critical Design Review).

  This approach will insure a more efficient control of Sellers by a GAC Itinerant/ Surveillance type and reduce the need for a resident Quality Control representative. A large percentage of equipment/Seller problems that become "panics" will be prevented by this method.

- A well defined Seller Requirement Document with adequate Quality Control input is utilized to minimize delays, additional travel, document disapproval, etc. generally caused by inadequate definition of, and misinterpretation of requirements.

- A statistical approach, such as the Bayesian Reliability Evaluation (Ref. 2), will be developed and applied to selected Sellers on testing subsystem equipment components.

  The Bayesian Reliability Evaluation is a "modern" statistical approach to reduce testing on the Component/Assembly/Subsystem level. The philosophy and procedures form the basis for the development of a rational and consistent structure for the design of experiments and for decision making in the face of uncertainty. The Bayesian approach is of particular utility in small sample situations, by utilizing past historical data such as that obtained during OAO test and flight experience.

- Develop a select Seller Source List for Space Projects. Historical data from Apollo/LM and OAO Programs will be utilized to certify selected suppliers based on proven capabilities, in order to reduce or eliminate GAC Receiving Inspection/ In-House Testing.

(Ref. 2) "Bayesian Statistics for the Reliability Engineer", Proc. IEEE Annual Symp. on Reliability, Jan. 1966.

- Develop OAO/LST Quality Workmanship Standards for equipment fabricated by or for Grumman.
- Review present OAO Flight Equipment Quality Control requirements imposed on Seller by GAC, and impose Quality Standard QES-0002 where possible in lieu of QES-0001 (Major) for the OAO/LST Program.

2.3.7.3 Quality Level Considerations

Table 2-4 depicts cost category comparisons by Quality System Levels and hardware criticality of typical Flight Equipment procured from various subcontractors. The matrix includes a man-rated vehicle, OAO Spacecraft and F-14 Aircraft Component/Assemblies and all comparisons are of a current build.

The equipment criticality column represents numbers assigned by Project Reliability for the OAO/LST Vehicle. Section 4.2.4, Availability Apportionment, describes the generation of these criticality ratings which represent a weighting of relative importance, on a scale of 10, for both subsystems and subsystem components. The Quality Control System Levels are assigned by Quality Control Program Management on the basis of equipment complexity and criticality within the vehicle or aircraft subsystems.

Comparisons of Quality System Levels for identical or similar types of equipment are identified by an "X" in the appropriate column. As an example, the Sub-System Modules (4) for the Titan III OAO/LST Vehicle would require the major Quality System Level of GAC Spec. QES-0001 to ensure mission reliability.

The Shuttle OAO/LST Vehicle as a result of Shuttle resupply shall permit application of "Off-The-Shelf" aircraft type equipment in lieu of hi-rel space hardware throughout the subsystems and therefore shall permit reducing the Quality cost per unit procured. NASA/GSFC concurrence for utilization of equipment in this category shall be required.

Table 2-4. OAO/LST - Shuttle Economic Study Quality Control Flight Equipment - Subcontractor Items - Quality Comparison

SUB-SYSTEM	EQUIPMENT CATEGORIES 1 - Available 2 - Avail. Req. Modific. 3 - State of the Art 4 - Development Type			TITAN III OAO/LST SPACECRAFT		TYPICAL OAO SPACECRAFT		TYPICAL LM SPACECRAFT		F-14 AIRCRAFT COMPONENTS		SHUTTLE OAO/LST SPACECRAFT		REMARKS
MODULE #1 Communication & Data Handling	Status	No. Req'd.	Equipment Criticality S/S	Quality Level Major/Minor QES 0001	QES 0002	Quality Level Major/Minor QES-0001	QES 0002	Quality Level Major/Minor QCP 2.11	QCP 2.12	Quality Level Major/Minor QES 0001	QES 0002/1	Quality Level Major/Minor QES 0001	QES 0002/1	
Diplexer (OAO)	2	2	7					X						Shuttle-based program with 12 to 18 month MTTF requirements can relax quality level specs on replaceable components.
Command Receiver (OAO)	2	4	10					X						
Narrow Band Transmitter (OAO)	2	1	5						X					
Command Decoder	2	2	10	X					X					
Telemetry Format Control	2		6	X					X					
On- I 10	2	3		X										
Board- Core	2	16	8	X				X						
Processor (OAO) Bulk Mem.	2	2		X						X				
CPU	2	3												
Comp. Oper. Monitor	2	1	7	X						X			X	
Narrow Band Tape Rec.	1	1	5					X						
Wide Band Tape Rec.	4	2	7					X						
Wide Band Transmitter (S-B)	2	2	7					X						
Comm. Detector/Verifier	2	2	9											
Power Amp. & RF Switch			7						X					
Wiring Harness									X					
Multiplexer	2	2	9					X						
Power Converter (Digital)	2	3	9											
Tape Rec. Interface	2	1	7											

Table 2-4. OAO/LST - Shuttle Economic Study Quality Control Flight Equipment - Subcontractor Items - Quality Comparison (Cont.)

SUB-SYSTEM	EQUIPMENT CATEGORIES 1 - Available 2 - Avail. Req. Modific. 3 - State of the Art 4 - Development Type			TITAN III OAO/LST SPACECRAFT		TYPICAL OAO SPACECRAFT		TYPICAL LM SPACECRAFT		F-14 AIRCRAFT COMPONENTS		SHUTTLE OAO/LST SPACECRAFT		REMARKS
	Status	No. Req'd	Equipment Criticality S/S 10	Quality Level Major/Minor QES 0001	QES 0002	Quality Level Major/Minor QES-0001	QES-0002	Quality Level Major/Minor QCP 2.11	QCP 2.12	Quality Level Major/Minor QES 0001	QES 0002/1	Quality Level Major/Minor QES 0001	QES 0002/1	
MODULE #2 Electrical Power														
Batteries (OAO)	1	6	8			X		X						
Battery Charge Control	3	12	9			X		X						
Solar Array	1		7			X								
Multiplexer	2		7	X				X						
Diode Box (OAO)	2		9			X			X					
Power Distribution Unit	2		10			X		X			X			
MODULE #3 Stabilization & Control														
Fixed Head Tracker	1	2	8											
Digital Sun Sensor Elec.	1	1				X								
Inertial Reference Unit	1	2								X				
Solar Aspect Sensor	1	1				X								
FWJC (Controller)	2	3				X				X				
Magnetometer (OAO)	2	2												
Fine Wheels	3	6				X							X	
Inverter	2	1	9			X		X						
Digital Sun Sensor	1	4	6	X		X								
Remote Decoder	2	2	10											
Multiplexer	2	4	10											
Magnetometer Torquer Bars	3	3												
Wiring Harness		1	8											
IRU Electronics		2												
Offset Tracker	4	1												
Magnetometer Elect. (OAO)		2												
Solar Aspect Sensor (OAO)	1	4				X								

Table 2-4. OAO/LST - Shuttle Economic Study Quality Control Flight Equipment - Subcontractor Items - Quality Comparison (Cont.)

SUB-SYSTEM	EQUIPMENT CATEGORIES 1 - Available 2 - Avail. Req. Modific. 3 - State of the Art 4 - Development Type			TITAN III OAO/LST SPACECRAFT		TYPICAL OAO SPACECRAFT		TYPICAL LM SPACECRAFT		F-14 AIRCRAFT COMPONENTS		SHUTTLE OAO/LST SPACECRAFT		REMARKS
MODULE #4 Pneumatics	Status	No. Req'd.	Equipment Criticality S/S 10	Quality Level Major/Minor QES 0001	QES 0002	Quality Level Major/Minor QES-0001	QES-0002	Quality Level Major/Minor QCP 2.11	QCP 2.12	Quality Level Major/Minor QES 0001	QES 0002/1	Quality Level Major/Minor QES 0001	QES 0002/1	
Gas Supply Tanks (OAO)	2	3	8						X					
Regulators (OAO)	2	2	9				X		X					
Solenoid Valves (OAO)	2	16	10				X		X		X			
Valves (Shut-Off) (OAO)	2	3	10				X		X		X			
Piping	2		8	X									X	
Wiring Harness			8											
Gas Jets (High Thrust)	3		9				X	X						
Pneumatic Connectors	3		9				X		X		X			
Fill and Dump System			8				X		X					
PRIMARY OPTICS														
Primary Mirror	4	1												
Secondary Mirror	4	1												
Optical Alignment Assem.	4	1												
Offset Tracker Fold. Flat	4	1												

2.4 SPACECRAFT SUPPORT-GROUND OPERATIONS

Spacecraft Support-Ground Operations comprises ground support equipment (GSE), logistics, trainers, training, publications, testing and facilities. Efforts in support of these elements include:

- Logistic Organization and Flow
- Maintainability Analysis
- Site Activation
- Technical Support Data
- Support of Manufacturing
- Subsystem Development and Integration Support
- Data Evaluation
- Experiment Support
- Services for Supply of Expendables
- Support for Computerization of Functional Test Plans and Procedures.

A task description summary of the major elements follows.

2.4.1 Ground Station

The OAO/LST program will modify and make use of the present OAO Ground Station. This Ground Station contains a 930 Computer which performs the following tasks:

- Updates a status board and test conductor consoles with current spacecraft status data.
- Receives and processes status data from remote sites.
- Prepares and transmits contact messages to remote sites.
- Supplies the support computer program system (SCPS) with selected altitude data.

The GSFC OAO Ground Station consists of three 930 XDS computers. One of these, Computer B acts as a backup to either the A or C computers.

The 930 XDS computer is a medium size general purpose computer (24 bit 32 K memory) with priority interrupt system and has a time sharing or cycle stealing process to handle various peripherals. A 2 million (6 bits) byte disc capability is provided in order to have rapid access to various resident programs and routines. These three computers actually make up two separate ground stations and are designed to support two orbiting satellites at the same time.

Each OAO ground station is used for real-time monitoring of the spacecraft status data. It presents this data on a large display board (approximately 8 ft. x 18 ft.) for group monitoring of the current status data. Individual subsystem monitoring is provided on various test conductor consoles. Quick responses to any spacecraft anomalies can be generated by use of the ground controller's console allowing command changes during a real time contact of approximately 10 minutes.

The "status display board concept" is applicable to any large satellite that has a large amount of status information to evaluate and the need to initiate ground actions to circumvent immediate problems. During the early phases of the LST flight, this type of operation is pertinent. When initial problems are corrected and the on board computer self test programs and control programs are verified under actual flight conditions the need to use the status display board to constantly monitor and evaluate data is lessened.

2.4.1.1 Modifications Requirements Due to LST

Program loading requirements of the On-Board Processor and increases to the experimentation data storage due to the wide band tape recorder will require modifications or replacement of the existing OAO unique peripheral interface equipments such as the command modulator and the OAO PCM telemetry interfaces (OPTIs). Telemetered data changes will require changes to the Status Display board nomenclature and the corresponding lamp locations. Due to construction techniques, replacement of the entire upper portion of the Status Board will be required.

Changes will also be required to update the test conductor consoles overlays and some growth to the displays on these consoles is estimated.

New bit synchronizers to work with the faster wide band tape recorder dumps are assumed to be required.

S-Band receivers at the remote sites will be required and it is assumed that changes to the STADAN facilities by 1976 will be adequate to handle the expected faster data dumps and uplink data command rates of the LST. The cost for STADAN facilities changes are not included in this study.

Ground Station costs are not impacted by Shuttle considerations.

2.4.1.2 Modification Requirements due to Computer Changeover

The existing ground station at GSFC will be updated from the present 930 computers to Sigma 7 computers. The 930's are no longer in production, and maintenance of obsolete computers will not be cost effective.

The Sigma 7 has a 32 bit word size addressable as eight bit bytes. Additional modifications to existing unique interface devices such as the OAO command output generator (OPCOG) and the OAO PCM telemetry interface will be required to work with the Sigma 7.

It is expected that new hardware would be required to update the X series circuits in the station to the newer integrated circuit T series type. Equipments such as the Parallel Input Extender (PINEX) and Parallel Output Extender (POTEX) would change due to the increased word size (24 bits to 32 bits) and the different timing requirements of the Sigma 7.

Modifications to existing interfaces to take advantage of the 32 bit word size and timing will be incorporated wherever possible.

Additional equipments that may require modifications or replacements are:

- CRT Parallel Interface
- Teletype Coupler
- Digital to Analog Converter Interface
- 360 System Interface
- Modern Interfaces
- Peripheral Switches
- Simulator Interface

Two Sigma 7 computers will be required, one acting as a backup. This dual concept has been proven with OAO experience to be necessary to allow for a sufficient uptime-downtime ratio. Another computer (3 total) will be required to update the Test and Integration Station.

2.4.2 Test and Integration Station

The Test and Integration Station provides the test engineer with the capability to execute spacecraft commands and monitor response data. In addition, the computer can monitor all data points from the spacecraft and inform the test engineer when an impermissible or unexpected change has occurred on other equipments. This capability provides constant spacecraft performance and detects any malfunctions that may occur. The existing Test and Integration

Station at GSFC will be modified for use during vehicle system integration as well as for support of the System Integration Test Stand used to integrate the spacecraft avionics.

The Test and Integration Station uses a 930 computer similar to the one used for the Ground Station. The same assumptions regarding the computer applies here as for the one applicable to the Ground Station. The commonality of the Test and Integration and Ground Station computers is maintained. One new computer is included with the station modification but is costed under item 1.3.

This station, with its computer, is moved with the vehicle from GAC to GSFC and to KSC. After launch, it is returned to start S/S integration for the next vehicle. Cycle repeats for each vehicle. T & I station changes required to work with new Sigma computer are:

	No. Req'd.
Parallel Input Extender (PINEX)	1
Parallel Output Extender (POTEX)	1
OAO PCM Telemetry Interface (OPTI)	2
OAO Command Output Synchronizer (OPCOG)	1
Command Modulator (COMO)	1
CRT Parallel Interface	1
Teletype Coupler (TTY)	1
Digital-to-Analog Converter Interface	1
Cabling Modification	
BIT Synchronizer *New Equipment	2
Test Conductor Console's Bi-Level and Analog Display Panels	

When launching the LST with a Shuttle, the station will not be required for tests on the launch pad. Payloads enclosed in the Shuttle will have a final checkout in the Shuttle hangar prior to the move out to the launch pad.

2.4.3 Programming

The following new computer programs will be required for the LST;

- Simulation programs for the entire vehicle for the study of guidance and control.
- Simulation of the power subsystem and loads to study the power requirements of the vehicle.
- Simulation of the vehicles real time command and control responses.

- Emulator of an on board computer for checkout of the on-board programs.
- Executive for on-board computer.
- Subroutines for Stabilization and Control, Data Processing, Command Processing, Power, Thermal, Modes of Operation, Experiments command and Operation.
- Computer self check diagnostics.
- Test and Integration checkout routines such as functional tests of the subsystems, EMC tests, vibration and thermal vacuum tests, prelaunch checks.

In addition to the new programs, modifications to existing programming for mission operations are required:

- Modification of all control console software, display board software and operating software.
- Modify the star position programs to LST requirements.
- Modify mission contact and scheduling programs.
- New experimenter data handling software requirements.
- Diagnostics for checkout of ground station.
- Documentation of all central control station software.
- Remote site software.

Programming is not affected by consideration of the Shuttle. It is assumed that only experiment software changes will be required when system modules are changed.

2.4.4 System Test Stand (STS)

A System Test Stand (STS) is a full scale framework of the LST spacecraft that is built to permit easy access to all areas without or within the spacecraft for rapid integration of the subsystems. Subsystems are mounted on the framework in their respective position in the LST, with identical cable runs. The STS also provides simulation of missing subsystems so that it can be operated while S/S modules are in vendor repair. One STS will be provided for the LST program.

The Cost of the STS is minimized by the use of the flight (prototype included) S/S modules. The Test and Integration Station will be used as the checkout station.

It is assumed that experiment packages will be maintained by the experiment vendor, though maintenance capability does exist with a STS.

2.4.4.1 Titan Launch

Subsystem development integration will be performed on the STS in parallel with the structure development and assembly, thereby reducing total development time and cost. This approach has shown to be cost effective in aircraft checkout and acceptance, and test schedules in this study are based on a STS program.

The STS can also be used for pre-installation test of S/S modules and experiments of follow-on vehicles in addition to providing integration of any changes as technology progresses.

2.4.4.2 Shuttle Launch

- Use STS as described previously.
- Use the STS to integrate new experiments with the spacecraft avionics for a resupply mission. It can provide a high level of confidence that the experiment change will be compatible with the avionics already in orbit.
- The STS can also provide a test bed for the spare modules keeping them in a "ready for installation" state, to support a resupply mission.
- Use the STS as bench maintenance equipment for repair of failed S/S modules, eliminating the need for procuring individual bench maintenance equipment early in the program.

  As the program progresses, and vendors are no longer supporting repair, their module acceptance stations, which have been paid for by NASA can be delivered to the LST test and maintenance area where NASA may now perform repair and refurbishments.
- Any additional interfaces unique to the Shuttle/LST will be tested with the STS.

2.4.5 Handling Equipment

In determining the requirements for handling equipment, the following additional assumptions were made;

- Shipment from GAC to Goddard and Goddard to KSC is made with LST "power-down", but with an air conditioned environment provided. Transportation will be by Guppy Aircraft with over-the-road transport between the airport and facility.
- Shuttle considerations do not impact shipping costs.
- In contrast to OAO, LST will be checked out, handled and transported in the horizontal position, except for vibration, magnetic survey and thermal tests. This approach is taken to avoid the large cost of major facility modifications. In addition, transportation between sites is only economically possible with the LST in the horizontal position.

2.4.5.1 Equipment List

The list is based on OAO experience. It is expected that future studies will be performed to define the exact requirements.

- Alignment Cube-Spacecraft - Required for reference to align various structural and add-on components to basic structure.
- Alignment Cube & Target - Telescope Support - Required for reference to align experiments and components to telescope support and for alignment with spacecraft.
- Alignment Gauges & Targets - For components (experiments, antennas, Solar Panels, S/S Pkgs.) to be aligned with spacecraft.
- Spacecraft Dolly - Combination handling, rotating dolly and support stand for use with workstand.
- Telescope Support Dolly
- Spacecraft Workstand - Platforms surrounding spacecraft to provide access to all parts of built up spacecraft. Sections break away for component installation and clearance. Overhead hoisting capability included for component handling.
- Telescope Support Workstand - This stand will fit together with the Spacecraft workstand to become an integrated test stand.
- Rotating Fixture - Required to orient the spacecraft and/or the telescope support in the vertical attitude for vibration tests and for cleaning.
- Sling Set - For hoisting the spacecraft and the telescope support.
- Spacecraft Environmental Cover with Air Conditioning Cart - For use with dolly for moving spacecraft between facility buildings while maintaining environmental control. Also used for operations outside buildings.
- Vertical Spacecraft Dolly/Support - Required for operations on a vertical spacecraft. (Work platforms will be temporary scaffold types.)
- Vehicle Covers/Soft Covers for protection within facility during shipping/handling operations.
- Optical Alignment Fixture - Modify OAO fixture - required for alignment of various spacecraft components with T.V. chamber table (air bearing).
- Weight and Balance Adapter - Modify LM equipment or build new E.I. - Required for moment of inertia determination of spacecraft and telescope support.
- Non-Magnetic Support Stand with Non-Magnetic Breakdown Platforms - For support and access to spacecraft during magnetic tests.
- Transporter - Air Conditioned - For over the road and air transportation of spacecraft, telescope structure (and possibly combination of both).
- Environmental Container Set - For transportation of experiments; subsystem packages, antennas and other vehicle components.
- Battery Handling Equipment - Installation equipment, checkout and handling carts, slings, temperature controlled package and storage equipment.
- Solar Panel Handling Equipment - Deployment aids, protective covers, handling containers.

- Nitrogen Conditioning Equipment - Used for pressure systems and for purging (such as during stacking operations). Use existing OAO equipment.

- Pneumatic Conditioning Equipment - For servicing the stabilization and control subsystem.

- Thermal-Vacuum Chamber Workstand - Support Stand with work platforms, access and penetration plates.

- Instrumentation and Service Lines Supports System - Routing and Support of lines leading from outside through vacuum chamber to vehicle.

- Shroud Support Equipment (Supplied GFE) - Sling Set, wheels (or Dolly) access platforms.

- Environmental Enclosure - Used for maintaining air conditioned and cleanliness levels within less clean environments.

- Interstage Adapter Handling Kit - Dolly, Sling, access platforms and adapter fixtures.

- Nitrogen Purge Conditioning Cart - For nitrogen purge of shroud during assembly. Use existing cards.

<u>Shuttle</u>

The Shuttle program will require the following additional equipment

- Shuttle interface equipment for use in loading LST into shuttle cargo bay.

- Docking Simulator - Used for mechanical and electrical checkout of docking interface.

Tentative operational sequence at launch site is:

a. Vehicle arrives at launch site in horizontal position.

b. Move to hangar clean room.

c. Take out of shipping container.

d. Inspect - visual.

e. Install solar paddles.

f. Power on - aliveness and functional test:

g. Install interstage adapter.

h. Transfer to vertical position

i. Assemble shroud and attach nitrogen purge lines.

j. Place on trailer and move to pad - continue purge.

k. Lift and install on booster.

l. Final checkout through LST RF link.

For the OAO/LST shuttle program only two of the four launch consoles will be required since there is no LST checkout on the pad. In addition, the tentative operational sequence (g) through (l) changes as follows:

- Assemble shuttle payload shroud if required and attach nitrogen purge line.
- Place on trailer and move to shuttle hangar.
- Mount in shuttle cargo bay.
- Connect LST/Shuttle umbilical.
- Move to pad in shuttle.
- No checkout on the pad.

2.4.7 Trainers and Training

No special trainers or formal training will be required for a Titan program.

However, the shuttle introduces the capability for resupply and retrieval missions for which shuttle astronauts must train. Resupply and retrieval will not require an EVA, but will be performed remotely with control by the shuttle astronauts from their cockpit.

An existing shuttle simulator is assumed, with its attendant "executive" shuttle characteristic program. The LST project will assume the cost of LST associated simulator models, programs and training for the LST Mission.

2.4.7.1 Requirements

- Three models will be supplied for shuttle simulator training: two of an LST with its docking ring, and one of the cargo bay portion of the shuttle with strong-back and service module. The two LST models are for a distance view and the other for a close-up of a docking operation. Special cameras for sighting on the models will also be included in order to provide the visual display in the shuttle cockpit as would be seen in a normal mission.

- Costs are based on experience with the LM Simulator, which required a docking simulation with special cameras, models and programs. The cost of this portion of the simulator was approximately 3 million dollars out of a total simulator cost of approximately 15 million.

- All LST/Simulator computer programs and their integration with the "shuttle program" is assumed included within the 3 million cost.

2.4.8 Publications

Formal publications will be kept to a minimum.

When considering the shuttle program a Shuttle Crew Procedure Manual for a LST resupply mission will be required.

2.4.9 Test and Checkout

The LST test and checkout program is designed to achieve maximum confidence in mission success. This will be accomplished by subjecting the spacecraft to a series of tests which will most economically verify all modes and functions. Whenever technically feasible, the stimuli and measurements provided for checkout will have excitation and verification of all operational and redundant modes of the system under test.

In addition to the efforts involved in actual testing, the following associated tasks will be required:

- Definition of the integration and checkout requirements.
- Definition of site activation/test interfaces for GSFC and the launch site.
- Generation of a single checkout plan for flight articles.
- Inputs into a General Test Plan for flight and development programs.
- Generation of test procedure outlines.
- Generation and update of test procedures.
- Checkout of the flight and development articles.
- Test planning and control, supervision of the "test team".
- Preparation of test reports to summarize and highlight test data.

2.4.9.1 Test Objectives

The major objectives of the LST test and checkout program are to:

- Verify that the static and dynamic structural integrity is consistent with the launch environment.
- Verify compatibility of the installed systems and experiments.
- Verify that all systems and experiments meet or exceed performance requirements.
- Perform test and checkout on all hardware for NASA approval and spacecraft acceptance.
- Reduce the risk of schedule delays by logically integrating the test and checkout of the spacecraft with the final phases of manufacturing assembly.

2.4.9.2 Assumptions

- Subsystem and experiment modules will be designed, developed and qualified (including thermal vacuum) prior to delivery to contractor.
- There is no requirement for pre-installation testing of the subsystems and experiment modules. Consistent with the design approach, each module is self contained and will undergo an acceptance test at the vendor. The vendor acceptance test will be approved by contractor and the actual test witnessed by contractor QC. All performance data obtained will be available for review by contractor test engineers.

- Thermal control for each module will be developed on the subsystem and experiment level since each is a thermally self contained unit. There is no interconnection between modules to a central heat transport system. Present design concepts are considering variable conductance heat pipes or louvers.
- The only costs considered that are associated with the manipulator are those for integration verification of the manipulator into the shuttle system.
- Thermal heat pipe systems have no active components.
- Solar panels will not be tested at the vendor. Panels will be installed and checked out at GSFC.
- The telescope alignment will be accomplished at the vendor.
- It is assumed that the support equipment engineers, together with the test engineers, accomplish the initial integration of the vehicle with the support equipment.
- The test planning effort includes test requirements definition and generation of a checkout test plan.
- To minimize cost, testing will be conducted on as high a level of assembly as practical and redundant testing will be minimized.
- A common test approach will be followed at each of the sites at which the vehicle will undergo test.
- During the period between actual checkout of each flight article a basic minimum number of personnel will be maintained actively on the program. When checkout of a subsequent vehicle occurs the personnel will be drawn from the appropriate contractor matrix organization to bring the staffing up to the required level.

2.4.9.3 Development Test Program

Figure 2-12 presents a typical OAO/LST development test schedule utilizing the mock-up, structural test article and system test stand. The major test elements used to arrive at the development test flow are presented in Table 2-5.

2.4.9.4 Flight Article Test Program

Figure 2-13 presents a typical OAO/LST test schedule for the first flight article. Differences between the schedules for a Titan and Shuttle are given in the explanations that follow. The major test elements used to arrive at the test flow are presented in Table 2-6.

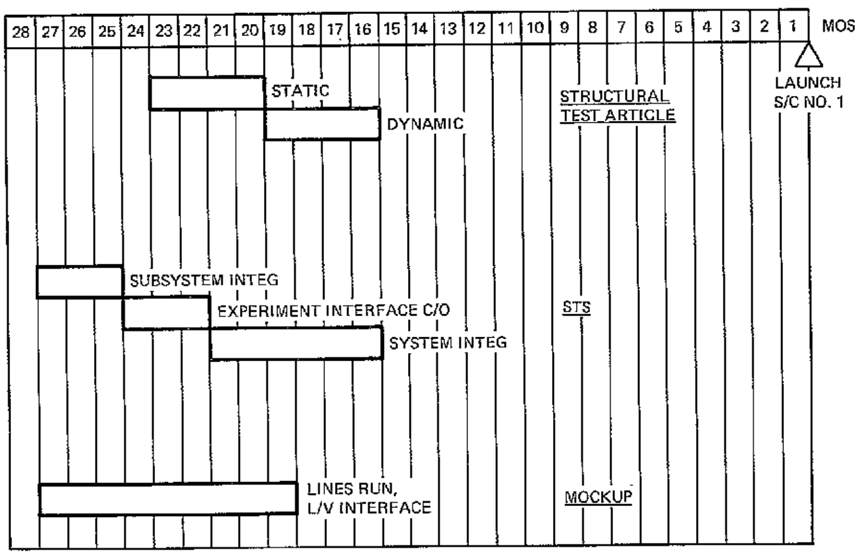


FIGURE 2-12. OAO/LST DEVELOPMENTAL TESTS
TYPICAL TITAN/SHUTTLE SCHED.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 2-5. OAO/LST Development Test Elements

TEST FUNCTION	PURPOSE	TEST FLOW PHASE	REQUIRED FOR TITAN LAUNCH	REQUIRED FOR SHUTTLE LAUNCH	REMARKS
1. Lines Run	Establish cable length and routing. Establish pneumatic lines routing and bend radii.	Vehicle manufacture	Yes	Yes	
2. Modules-Mechanical C/O	Develop/verify module installation/removal.	Vehicle design and manufacture	Yes	Yes	Shuttle requires additional development of latching mechanism and connectors.
3. Launch Vehicle Interface	Verify LST/launch vehicle form factor compatibility.	Vehicle manufacture	Yes	Yes	
4. Docking	Verify LST/Shuttle docking/ separation capability.	Vehicle manufacture	No	Yes	Shuttle requires development of docking mechanism. Docking is not applicable to Titan.
5. Manipulator/LST Integration C/O	Develop/verify manipulator/LST removal/installation of subsystem and experiment modules.	Manipulator Design and development	No	Yes	Manipulator is not required for Titan.
6. Heat Pipes	Verify pressure integrity of thermal control heat pipes.	Development test phase	Yes	Yes	Pressure test only. Heat transfer to be verified during thermal/vac.
7. Vibration	Verify LST structure's ability to withstand launch dynamic environment.	Development test phase	Yes	Yes	Vibration levels can be reduced and/or verified analytically, for shuttle, since Titan design launch environment is more severe.
8. Steady State Loads (Static)	Verify LST capability to with-stand inertial loads of liftoff, boost, docking, and re-entry.	Development test phase	Yes	Yes	Same as above for static loads.
9. Systems Test Stand (STS)	Off vehicle development of inte-grated subsystem and experiment modules.	Development test phase	Yes	Yes	

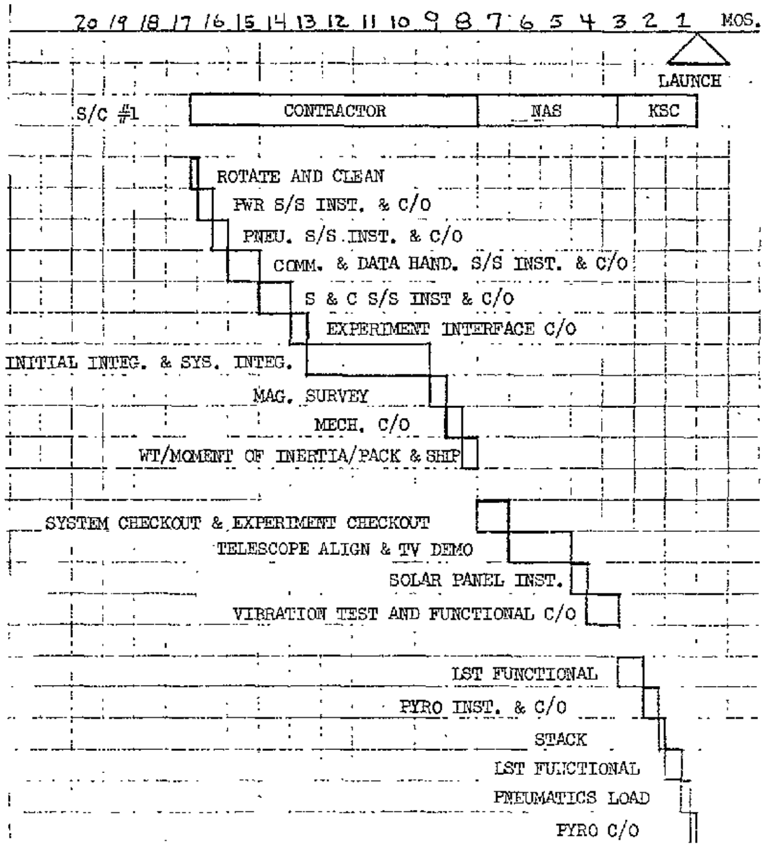


Figure 2-13. OAO/LST Flight Article Test and Checkout

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 2-6. OAO/LST Flight Article Test Elements

TEST FUNCTION	PURPOSE	TEST FLOW PHASE	REQUIRED FOR TITAN LAUNCH	REQUIRED FOR SHUTTLE LAUNCH	REMARKS
Subsystem					
1. Power S/S Module Installation	Verify structural/subsystem interface. Verify electrical power distribution to all other module positions.	Test & checkout/ pre-integration	Yes	Yes	Solar panels will be simulated only. Flight type batteries will be used for checkout. Prior to launch, batteries will be replaced.
2. Pneumatic S/S Module Installation	Verify structural/subsystem interface. Verify pneumatic integrity throughout vehicle.	Test & checkout/ pre-integration	Yes	Yes	Module for Titan launch vehicle will not have pneumatic "Quick Disconnect" interface with spacecraft.
Stability & Control S/S Module Installation	Verify structural/subsystem interface. Verify "Copper Path" integrity between S&C S/S module & all other module positions.	Test & checkout	Yes	Yes	
4. Communications & Data Handling S/S Module Installation	Verify structural/subsystem interface. Verify "Copper Path" integrity between C&DH S/S module and all other module positions.	Test & checkout/ pre-integration	Yes	Yes	
5. Experiment Integration	Verify structural/subsystem interface. Verify "Copper Path" integrity between experiment module simulators and all other module positions.	Test & checkout/ pre-integration	Yes	Yes	All experiment test equipment will be supplied with the experiments as GFE. Where experiments are not available, a simulator will be utilized to duplicate the characteristics of the experiment.
6. Heat Pipe C/O	Load heat pipes and verify pressure integrity.	Test & checkout	Yes	Yes	

Table 2-6. OAO/LST Flight Article Test Elements (Cont.)

TEST FUNCTION	PURPOSE	TEST FLOW PHASE	REQUIRED FOR TITAN LAUNCH	REQUIRED FOR SHUTTLE LAUNCH	REMARKS
System					
1. Initial Integration	Verify LST System Performance on an integrated basis. Obtain System baseline data for subsequent testing.	Integration System & EMI Verification	Yes	Yes	Test performed with GSE plugged into the modules for simulation and simulation inputs/outputs.
2. System C/O	Verify under controlled EMI environment that the installed system is compatible. Demonstrate LST performance in typical mission modes.	Integrated system & EMI verification	Yes	Yes	Test performed with minimal support equipment. Vehicle will be essentially flight configuration.
3. Weight & Moment of Inertia	Determine LST weight and moment of inertia.	Weight & moment Pack and ship	Yes	Yes	
4. Thermal/Vacuum	Verify functional operation of all subsystem components under thermal/vacuum conditions.	GSFC Test phase	Yes	Yes	Test will be accomplished at GSFC.
5. Mechanical C/O	Verify solar panels and sun shade deployment. Verify mirror alignment capability.	Mechanical C/O	Yes	Yes	
6. Magnetic Survey	Measure the 3 axis magnetic dipole of LST and provide for compensation.	Mechanical C/O	Yes 1st vehicle	No	Test will be accomplished in a cleared area for Titan program. For Shuttle launch, vehicle-compensation can be accomplished during in-orbit module replacement.
7. Telescope Alignment	Adjust telescope alignment prior to shipment to launch site.	GSFC test phase	Yes	Yes	
8. Experiment modules checkout	Verify "Copper Path" integrity between experiment modules and spacecraft.	GSFC test phase	Yes	Yes	
9. Vibration test	Subject the LST to a low level vibration test with experiments installed.	GSFC test phase	Yes	Yes	To uncover workmanship defects that may not be discernible by unstressed functional checks.

- Checkout Activities at Contractor: The testing flow begins with the completion of the basic vehicle structure with the required harness and includes the installation of the subsystems modules. Each subsystem module is checked in the spacecraft as well as the experiment interfaces. Any experiment that is not available for interface checking and has a major interface with the spacecraft will require the use of an interface simulator. Further in the flow, the systems tests will integrate the vehicle hardware and perform acceptance demonstration to the NASA.
- Vehicle Checkout at GSFC: After completion of normal inspection procedures the vehicle will have the experiments installed, the telescope aligned, and undergo a major system's test to include all functions. After which, the vehicle will be placed in the chamber and undergo thermal/vacuum demonstration. Prior to undergoing an acceptance vibration test the solar panels will be installed. The vehicle will then undergo an acceptance test, after which, the telescope alignment will be checked and a complete functional test will be performed to demonstrate the spacecraft flight readiness after vibration and thermal vacuum. The GSFC test phase is identical for the Shuttle and Titan programs.
- Launch Site Operations: Launch site operations will be identical for the first vehicle of each program. Upon arrival at the launch site the vehicle will be inspected for shipping damage and undergo a complete functional test, including a telescope alignment check, to verify flight readiness. The pyrotechnic devices will be installed and checked and the vehicle will then be stacked into the launch system. Prior to launch the vehicle will undergo a reduced functional checkout to assure flight readiness, the pneumatics will be loaded and a final check of the pyro devices will be made. For subsequent flights on the Shuttle program the launch site checkout will be reduced since there will be no post-stack activities. Table 2-7 lists the Launch Site test elements.

2.4.10 Facilities

A preliminary survey for preparation and activation of facilities required to support an LST program was performed. The use of existing facilities, modified and improved to meet program requirements was considered. Table 2-8 lists the requirements for these facilities. Shuttle considerations do not substantially impact the facility requirements.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 2-7. OAO/LST Launch Site Test Elements

TEST FUNCTION	PURPOSE	TEST FLOW PHASE	REQUIRED FOR TITAN LAUNCH	REQUIRED FOR SHUTTLE LAUNCH	REMARKS
1. Telescope Alignment Checkout	Verify misalignment capability.	Pre-stack checkout phase	Yes	Yes	
2. LST Functional	Verify subsystem and experiment modules are functional.	Pre-stack checkout phase	Yes	Yes	
3. Pyro Installation and checkout	Pre-launch installation pyro devices and pyro system C/O.	Pre-stack checkout phase	Yes	Yes	Shuttle - Verify interstage pyros.
4. Pneumatic Load and Checkout	Pre-launch loading of pneumatic subsystem and checkout.	Pre-stack checkout phase	No	Yes	LST loading accomplished prior to loading vehicle into Shuttle.
5. Pneumatic Load and Checkout	Pre-launch loading of pneumatic subsystem and checkout.	Stack checkout phase	Yes	No	LST loading accomplished after stacking vehicle on Titan.
6. LST Functional	Verify subsystem and experiment modules are functional after stack.	Stack checkout phase	Yes	No	As per assumption #10 Section II, payloads will not be checked on the launch pad for the Shuttle program.
7. Pyro checkout	Verify interstages pyro and resistance.	Stack checkout phase	Yes	No	

Table 2-8. Facility Requirements

Facility	Location	Requirement	Work Effort
(1) Program Administration			
1. Prime Offices	GAC P1 25/5	25,000 Sq. Ft.	Renovate
2. Action Center	GAC P1 5	2,000 Sq. Ft.	Refurbish, Displays
3. Reproduction	GAC	Existing	None
4. Documentation	GAC	Existing	None
5. Publications	GAC	Existing	None
6. NASA Team	GAC P1 25	1,000 Sq. Ft.	Refurbish
7. Off-Site Offices	Goddard/KSC	1,000 Sq. Ft. Ea.	Rentals
(2) Computer Services			
1. GDS	GAC	Existing	None
2. Analog	GAC P1 5	Existing	None
(3) Vehicle Simulation			
1. Models	GAC	Existing Model Shop	None
2. Soft Mockup	GAC P1 5	Mockup Hangar	Refurbish
3. Inertial Mockup	GAC P1 4	Available Hangar	Transport to Launcher Vendor
4. Lines Run Mockup	GAC P1 5	Mockup Hangar	See "Soft Mockup" for Hangar Rehab.
(4) Vehicle Manufacture			
1. Detail Parts	GAC P1 02	Existing Shops	
2. Sub-Assembly	GAC P1 02	Existing Shops	Minor Improvements
3. Tool/Shop Support 4. Sub-Systems	GAC P1 02, 03, 33	Existing Shops	
5. Final Assembly	GAC P1 05	OAO Clean Room	Jigs/Fixtures
6. Mfg. Inspection	GAC P1 05	LM Final Assy. Room	Refurbish
7. Shroud	GAC P1 02	Existing Shops	None
8. Acceptance C/O	GAC P1 05	LM F/A Room	See Mfg. Inspection
(5) Research/Development			
1. Development Testing (Cold Flow Facility)	GAC P1 05	Piping, Fixtures, Stands	Site Rehab.
2. Research/Experiments (Systems Test, Communications, EMI, Meteorite Shields, Fluids)	GAC P1 14, 26, 31, 05, 12	Minor Improvements	Power, Air, Piping Partitions

Table 2-8. Facility Requirements (Cont.)

Facility	Location	Requirement	Work Effort
(6) Vehicle Test			
1. Structural Test (Environmental Lab)	GAC P1 05	Rehab.	Site Activation
2. EMI Radiation (EMI Chamber)	GAC P1 05	Rehab.	Site Activation
3. Weight/Balance/Align. (OAO Clean Room)	GAC P1 05	Partition, Hoist, Fixture	Installation
4. Magnetic Survey (Magnetic Free Area)	GAC P1 14	Ballon, Compressor	Site Activation
5. Thermal Vacuum (Thermal Chamber)	NASA/Goddard	24' x 40' Chamber	None - by NASA
6. Acceptance Test (NASA/Goddard)	NASA/Goddard		None - by NASA
7. STS (OAO Clean Room)	GAC P1 05	SITS Frame, Computer Room	Fabrication, General Erection
(7) Test/Support/Control			
1. Test Integration Sta.			
(Mfg./Repair Shop)	GAC P1 33	Utility Mods.	Gen'l. Improvements
(Operations Room)	GAC P1 05	Partitions, Floor, Rearrange	Gen'l. Renovation
2. Qual. Test (Q.C. Labs)	GAC P1 10	Testing Labs, Existing	None
3. Product Support			
(GSE Fab.)	GAC P1 02, 03, 05	Shop Modifications	Minor Rehab.
(Spares/Supplies)	GAC, NASA	Warehousing	None
(Support/Hold Areas)	GAC, NASA	Hoist, Fixtures, Utilities	Renovate Plt. 04 Hangar
4. Training (Training Centers)	GAC, NASA	Mockup Facility, SITS Equipment	Renovate and Improve Plant 38
(8) Material			
1. Warehousing (Warehouses)	GAC	Existing Bonded Areas	
2. Receiving			
(Receiving Docks)	GAC		Minor
(Receiving Inspection)	GAC P1 24	Existing Inspection Lab	Improvements
(Shipping)	GAC	Existing Shipping Fac.	

Table 2-8. Facility Requirements (Cont.)

Facility	Location	Requirement	Work Effort
(9) Operations/Services			
1. Control Centers			
(Control/Surv.)	GAC P1 05	SACE Room	Computer Room
(Control/Surv.)	NASA/Goddard		2500 Sq. Ft.
(Control/Surv.)	NASA/KSC		
2. Launch Operations			
(Assembly/Checkout)		NASA site Prep.	
(Mating)	NASA/CKAFB	GAC Support Offices	
(Pre-Launch C/O)	NASA/KSC	and C/O shop	Renovate
(Launch Control)	NASA/KSC		
3. Custodial Services			
(Clean Room Mtce.)	GAC OAO Fac.	Maintain NASA	Clean/Supply
(Final Assy. Room MTCE)	GAC LM F/A	Requirements	Uniforms, etc.
4. Recurring Technical Services			
(Facilities Dept.)	GAC	Liaison, Coordinate, Interface, Minor Change	
5. Utilities			
(Power)	GAC	Assume 250 kw/4000 hrs/yr.	
(Communications)	GAC/NASA	TWX/Telemetry	

2.4.11 Orbital Support

Orbital support involves all the efforts directly related to spacecraft operation while it is in orbit. It comprises tracking, data acquisition, control, data processing and data analysis. It also involves the efforts for tracking and telemetry coverage of the launch vehicle from lift-off through spacecraft separation.

With updated ground station equipment, the OAO Operations Control Center (OCC) will become the OAO/LST OCC. This center will receive data from the spacecraft via microwave and high speed data links between GSFC and remote field sites, as presently performed for OAO. These field sites form the NASA Space Tracking and Data Acquisition Network (STADAN), which also performs the task of tracking the spacecraft. Ground tracking and early real time spacecraft status are also obtained with the assistance of the Manned Spacecraft Flight Network (MSFN). Appropriate organization and control procedures provide for coordination of the efforts between STADAN and MSFN.

Some primary functions of the OCC are:

- Coordinate and direct the overall OAO/LST operation.
- Serve as the interface between the support computer programming system (SCPS) and the field site stations.
- Generate sequences and commands for transmission through each station to the spacecraft for the execution of the experiment program.
- Transmit the sequences to the stations.
- Accept status and experiment data from the stations.
- Display selected data.

As the spacecraft data are fed back from the remote sites they will be processed in two areas:

- Real-time processing operations are performed by the Control Center Programming System (CCPS) during the contact. The Sigma 7 computer will analyze data from the spacecraft and drive all real-time displays such as the status display board, strip chart recorders, CRT, experiment displays, event printer, snap shots, commands, schedules and contact schedule changes.
- Support computer processing (SCPS) will compute the actual spacecraft altitude from selected spacecraft status data.

During post-contact time, an in-depth analysis is performed on the data received from the last contact. From the analysis, personnel will monitor spacecraft trends and compare them with predicted trends and determine the cause and effect in case of spacecraft anomalies. When required, corrective action is taken.

The Shuttle program introduces a new interface with the Manned Spacecraft Center (MSC) which is not required for Titan launch. An initial functional configuration of the interface is shown in Figure 2-14. With the Shuttle introducing in-orbit checkout prior to spacecraft release, the MSFN stations now must provide the data link for checkout in addition to launch tracking and early-orbit communication assistance. Control of the Shuttle is by MSC. Control of OAO/LST checkout is by GSFC. Additional organization and control procedures will be required to assure a coordinated effort for crew safety and a successful spacecraft deployment.

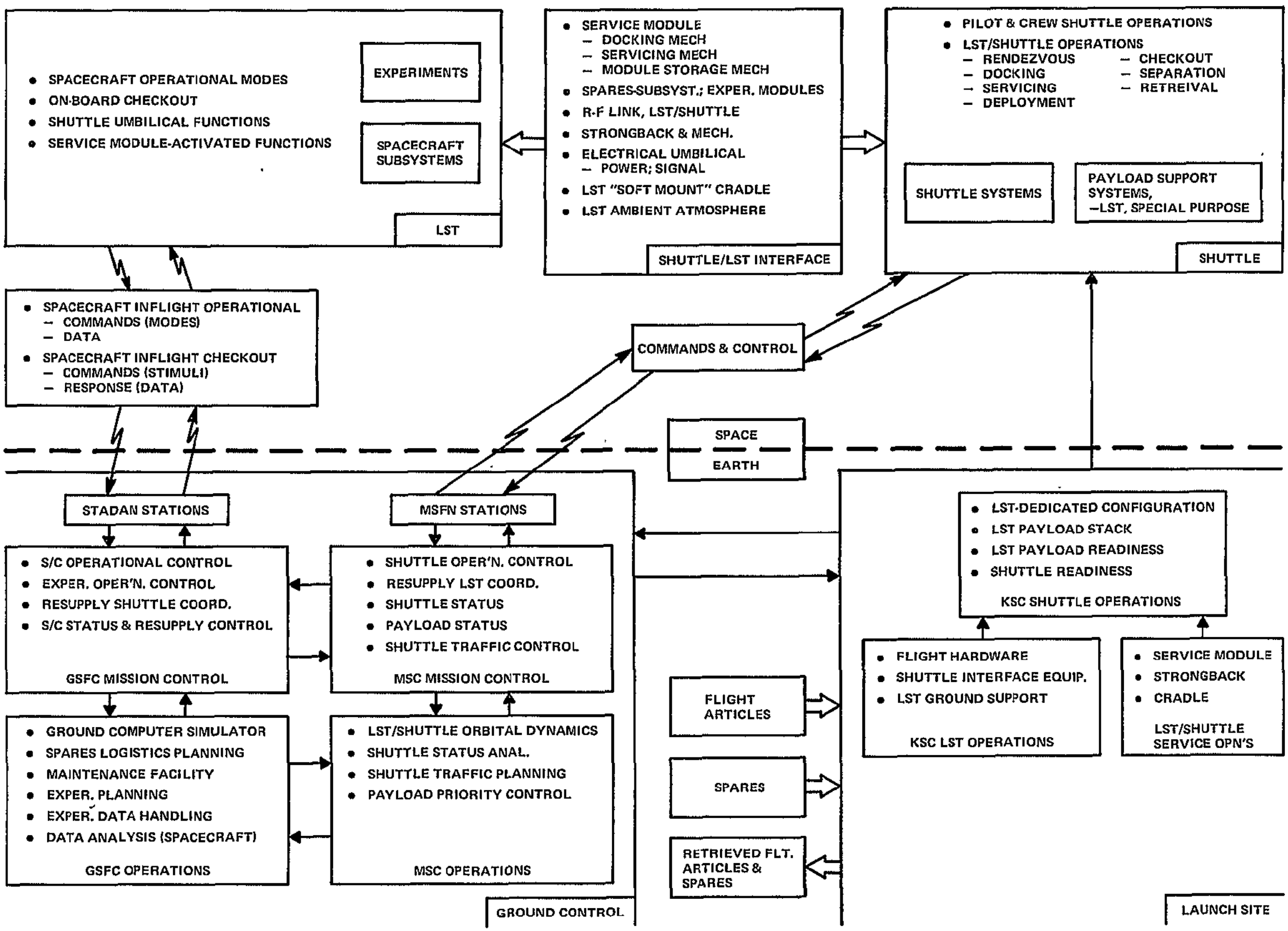


Figure 2-14. Functional Configuration - LST/Shuttle Operations

2.5 LAUNCH VEHICLE CONSIDERATIONS

2.5.1 Launch Environment Comparison - Titan and Shuttle

The Titan IIID7, which does not have a transtage as does Titan IIIC (a transtage is necessary for specialized orbits such as synchronous or near polar), can place larger payloads into conventional near-earth orbits. A payload capability envelope for the Titan IIID7 is given in Fig. 2-15. It is seen that the LST is well within the Titan IIID7 capability for near-earth orbit.

The following data show required design loads for the two Titan vehicles and the Shuttle:

Preliminary Rigid Body Design Loads Comparison (Flt x 1.5)

Condition	Titan IIIC	Titan IIID7	Shuttle
Boost Axial Compression	10g	9g	4.5g
Thrust Axis - Tension Rebound	5g	3.75g	
Lateral Steady State	5g	2.25g	3.75g

An examination of the three major design conditions reveals the following:

- Longitudinal Loading - It appears that axial compression will be more critical than tension rebound in all cases. The shuttle axial loads are approximately one-half (1/2) of the Titan environments.
- Lateral Loading - It can be seen from the data above that the maximum lateral loading on the Titan IIIC is substantially higher than the Titan IIID7. This is due to the unsymmetrically weighted kick stage that causes strong coupling between orthogonal mode directions. For the purposes of this comparison we obtain a lateral Shuttle condition of 150% of the Titan IIID7 environment. The Shuttle however can provide at least two lateral support levels - probably at each end of the spacecraft, while the present LST-Titan prime support is only at one level (with the possible addition of aft end sway bracing). This lower loading coupled with a more favorable support pattern probably would reduce an LST-Shuttle lateral environment to the same as an LST-Titan IIID7. As a very preliminary estimate, the axial load environment reduction (50%), (assuming a corresponding reduction in the shock, vibration and acoustic environment of a well isolated shuttle payload), might reduce the weight in the Structural-Mechanical area by about 20%.

There are additional factors which could result in savings due to the softer shuttle ride. These are:

- Materials - The lower loads may allow the use of aluminum instead of titanium in several structures of the GSFC design.

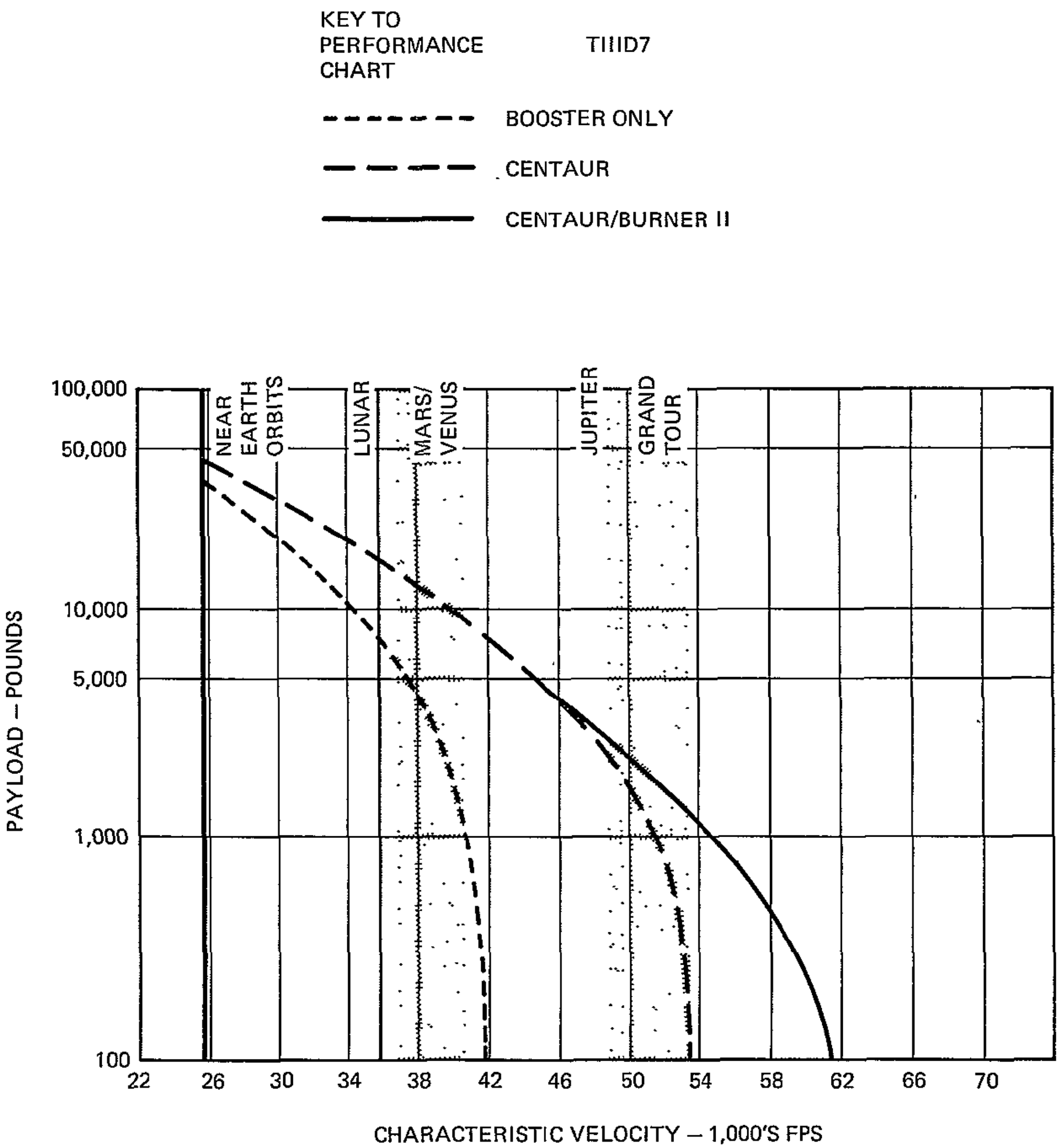


Figure 2-15. Titan IIID7 Payload Capability

- Testing - The sheer size and high accuracy requirements will extend beyond the present environmental test facility capabilities in some areas. It is possible that existing facilities may be adapted for the less harsh shuttle environment.
- Fabrication and Tooling - Again, smaller loads, lighter structure, are more likely to be adaptable to present facilities.
- Failure Contingency - Lower loads should decrease possibility of failure, particularly if baseline design is not modified.
- Lower Vibration Environment - In the spacecraft compartment much OAO equipment is used. The Titan environment probably would entail a requalification program, whereas the shuttle's more benign environment probably will save the cost of requalification of these equipments.

2.5.2 Shuttle Characteristics

2.5.2.1 Capability

The baseline shuttle design selected for the economic study was GAC Design 518, consistent with major designs now being investigated for NASA by other contractors. The cargo bay volume is approximately 15 feet diameter by 60 feet long. The envelope of weight capability vs orbital altitude and inclination are given in Fig. 2-16 in the series of curves labeled "Design 518". A detailed acceleration profile is given below:

Condition	N_x(g)	N_y(g)	N_z(g)
Max Accel	+3.0 -1.30	±1.0	+2.5 -2.7
Entry	-0.13	±0.1	-2.2
Landing	-1.30	±0.1	-2.7
Maneuver	-0.7	±1.0	±2.5
Rebound & Lift Off	+1.45	±0.5	±0.8

2.5.2.2 Interface With LST

(a) Structural

1. Lateral and longitudinal support is provided in two planes to avoid weight penalty of cantilevered support.
2. Deployment/Retrieval - The Shuttle will provide deployment, which will be rotational until LST is outside cargo bay. Deployment mechanism will include a docking mechanism for capturing LST for servicing, module replacement or return to earth.
3. Shrouding - LST can be transported to orbit within a pressurized module with thermal control or simply installed in the unpressurized bay. Dry nitrogen purge will be used for protection of optics and electronics during hold prior to lift-off.

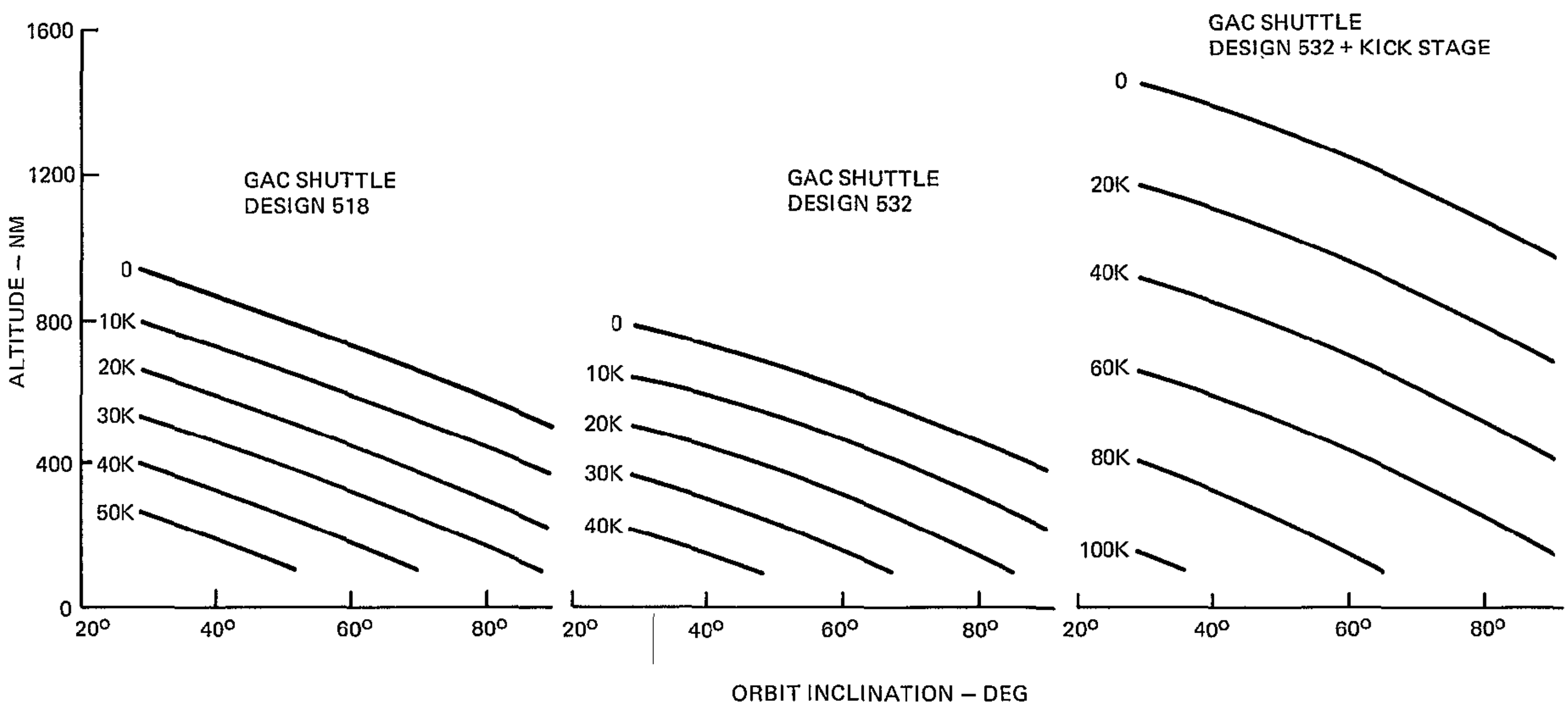


Figure 2-16. Shuttle Payload Capability

(b) Electrical

1. Power available from Shuttle for use by LST:

   Type: D.C. 120 Volts (may become 28 volts)
   A.C. 400 Cycles 120 Volts.

   Quantity: 500 Watts available. More could be made available if necessary.

2. RF orientation data updating

2.5.2.3 Docking

The permissible envelope of the shuttle in docking is summarized below:

Distance, Angle and Velocity Alignment

Parameter	Baseline Design
Miss Distance Centerline	±15 in.
Miss Angle Centerline	±4 degrees
Rotation Angle	±4 degrees
Contact Velocity	0-0.5 ft/sec

Fully automatic systems have not yet been developed. Manual systems have been well demonstrated in Gemini and Apollo. Size of shuttle and offsets between eyeball, docking ports and centers of gravity may generate real or apparent control-axes cross-couplings during docking. These problems will be defined by simulators and solved during the development of the shuttle. It appears reasonable to assume standoff docking manually controlled with optics and/or closed circuit TV and sensors aids will be the mode of docking.

The docking mechanical means will be androgynous, comprising two sets of leaves arrayed in conical fashion. One set is stationary and located at the base of the LST spacecraft structure. This docking ring will have a 60 in. dia. clear opening through its center. The other set, which is mechanically articulated, is located at the end of the service module attached to the shuttle. The usual nose docking by the shuttle will thus not be employed; instead, docking with the LST deployment and service module will require crew training through simulation. The mating conical leaf docking ring design allows great latitude in approach parameters, as shown in the data above, and greatly facilitates a manual docking procedure.

The articulated docking ring, which is stowable and deployable and which can vary leaf angle, can also rotate through 360° and lock at any of four stations 90° apart. Docking operations will be monitored by closed circuit TV augmented by three-dimensional capability for accurate depth perception, so that the operation may be quickly and easily accomplished.

Regarding visibility and illumination in docking, the solar angle diagram Fig. 2-17 gives the acceptable range. Sunlight incidence angles between 60 and 140 degrees are acceptable. For sun angles of less than 60 degrees, sun shafting through the docking viewport or sun incidence causing veiling (light scatter in the viewport optics) are distinct possibilities. For sun angles of greater than 140 degrees, the Shuttle's own shadow may cause obscuring of the LST docking port and target.

2.5.2.4 Service Module

After docking with the LST, the service module has the capability to remove and replace modules in both the spacecraft subsystems and experiment groups. The service module is illustrated in Fig. 2-18, lower left, in which the storage containers for modules to be replaced are clearly shown. A typical sequence of module exchange is shown at lower right. This procedure is monitored by three-dimensional television, highly desirable for precision placement of the modules.

The prime feature of the service module is that package exchange is accomplished by remote manipulator, not by astronauts directly in an EVA mode. Thus the spacecraft and equipment to be handled need not be man-rated, thus enhancing crew safety and generating savings in lead time and cost. Fig. 2-19 shows the manipulator operating with the subsystem modules (left) and the experiment modules (right).

The manipulator capability follows:

(1) Extract and replace any of three kinds of modules:

- Rectangular boxes 48" x 90" x 18" and up to 2000 lbs in weight. Fig. 2-20 shows a typical module.
- Wedge shaped modules located above rectangular boxes in experiment compartment, 32 in radial depth (100 in OD) x 37 in average height, x 70 in chord. Typical experiment packages are shown in place in Fig. 2-21. Weights of these packages are up to 500 lbs.
- Cylindrical on-axis instrument module 86" long x 54" diameter, approximately 1000 lbs, also shown in place in Fig. 2-21.

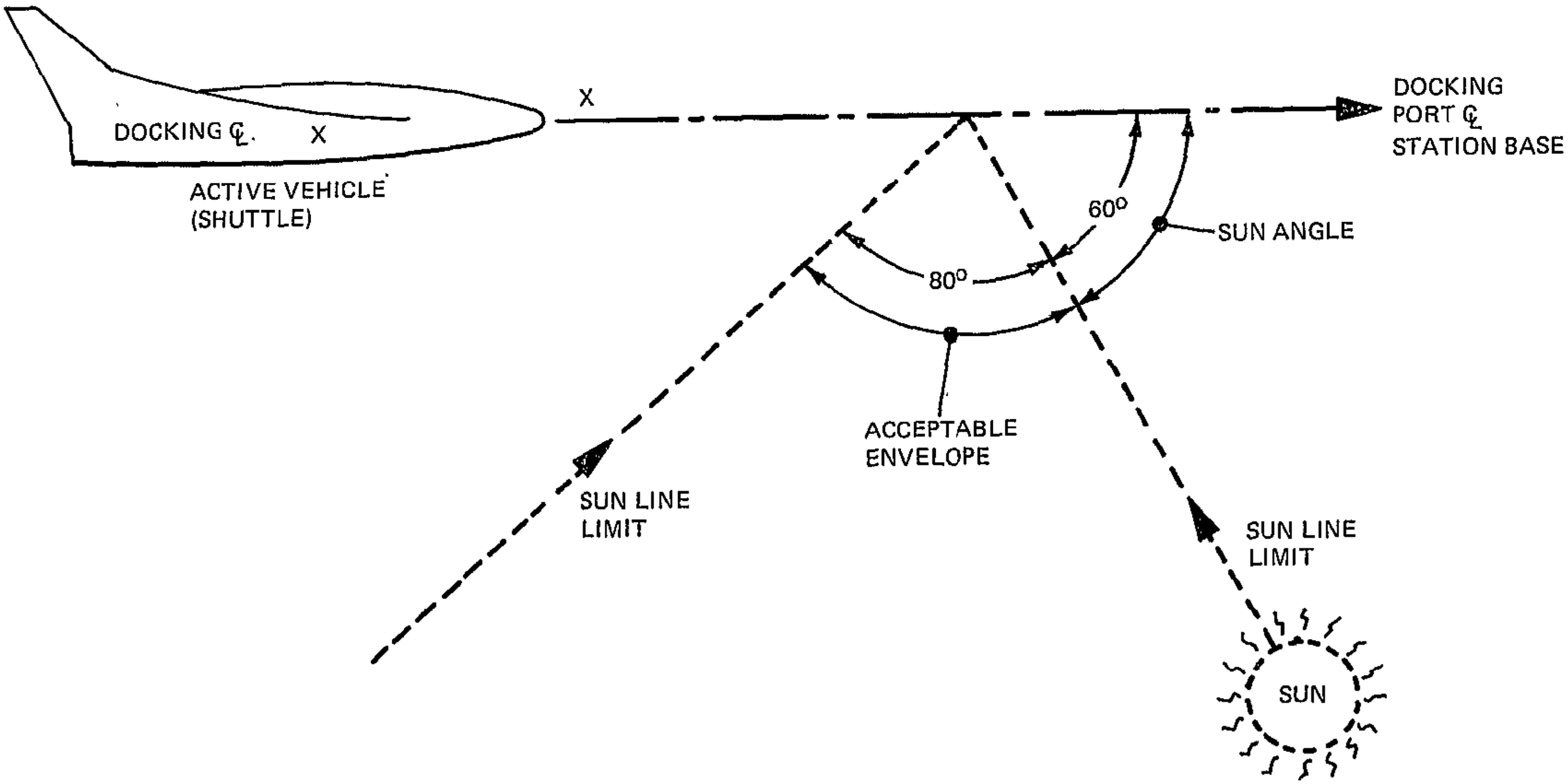
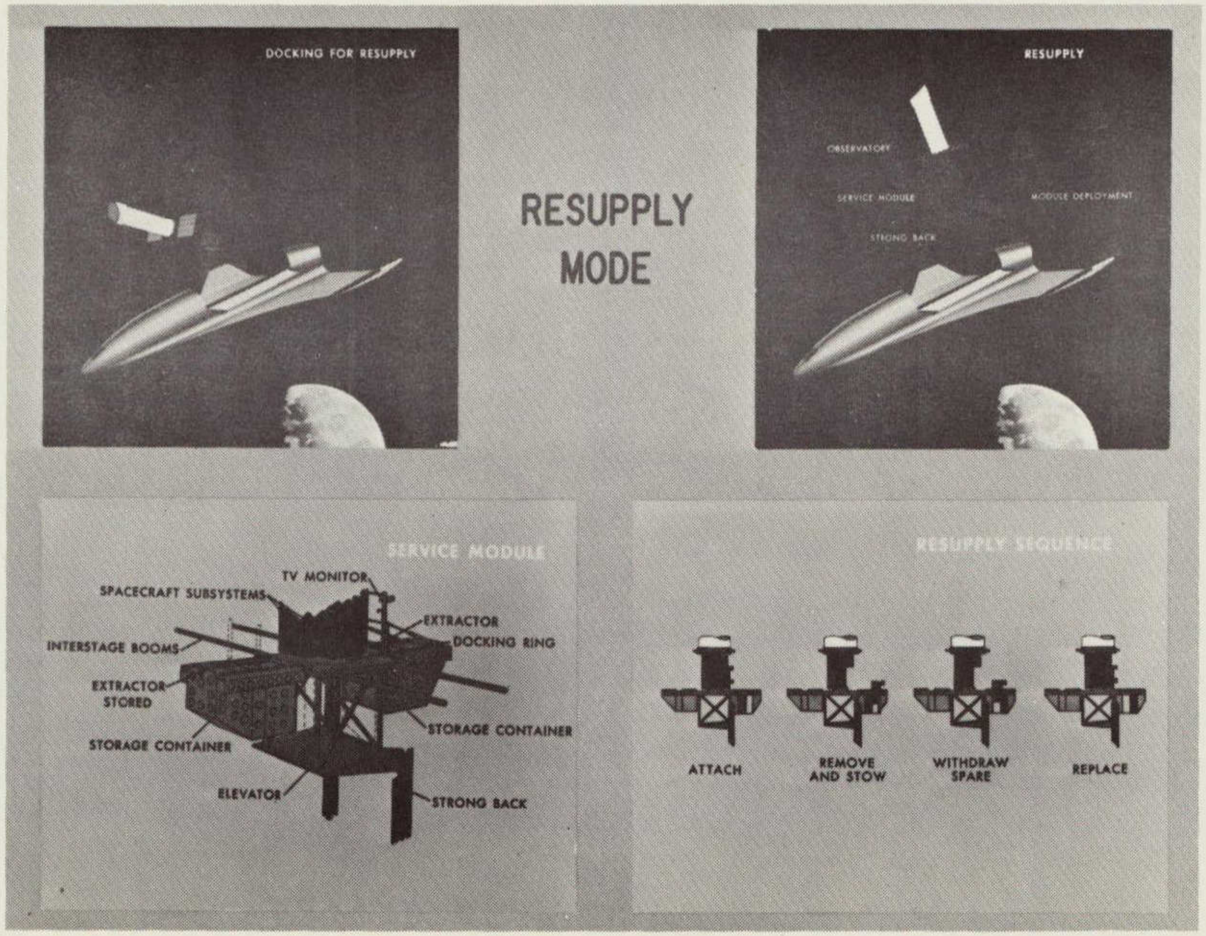
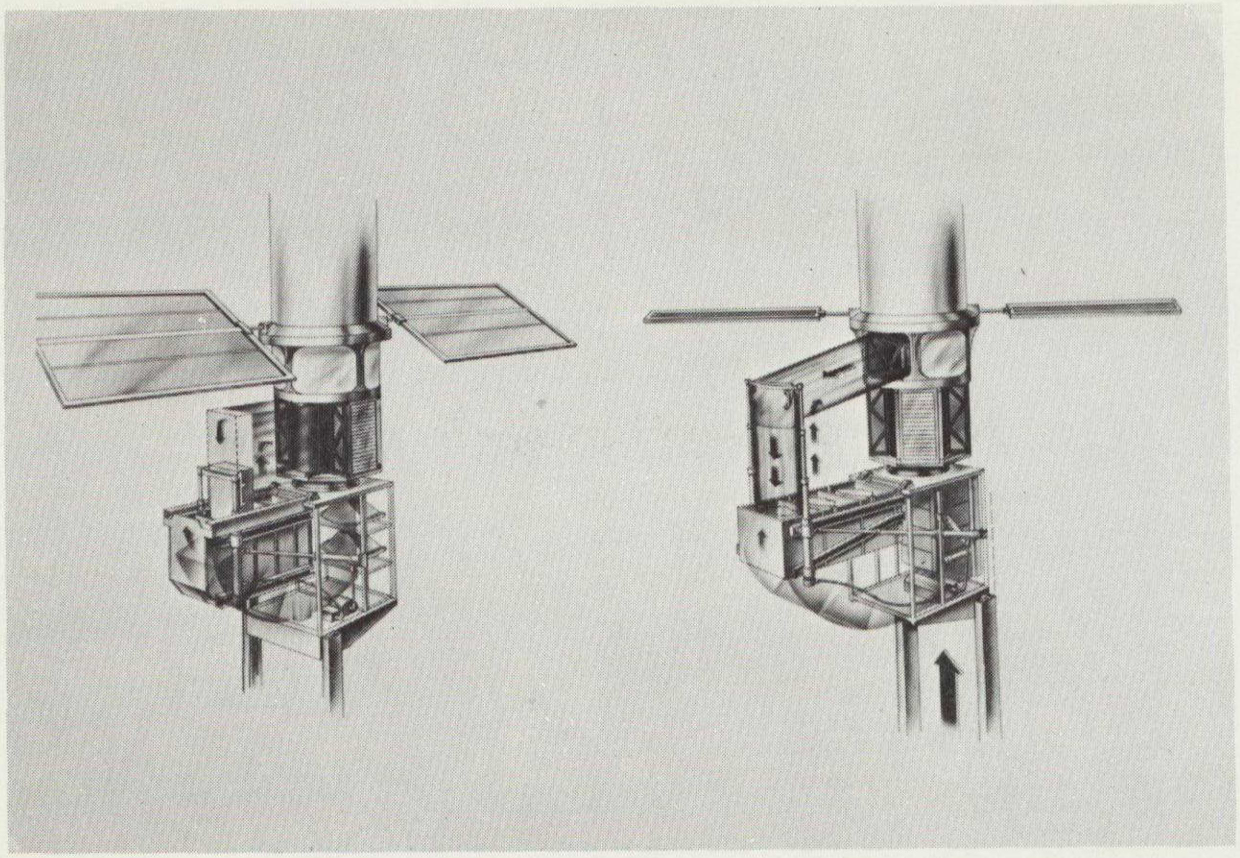


Figure 2-17. Docking Visibility Restraints



SUPPLIED BY GSFC

Figure 2-18. Resupply Mode



SUPPLIED BY GSFC

Figure 2-19. OAO/LST Remote Manipulator

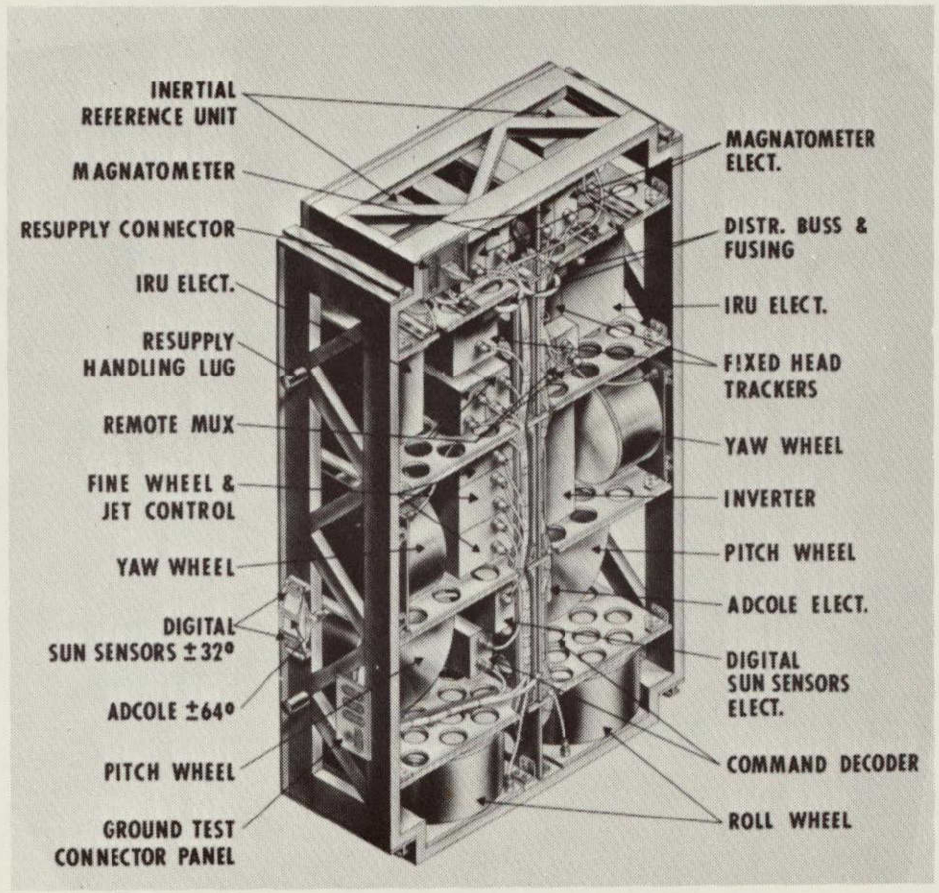


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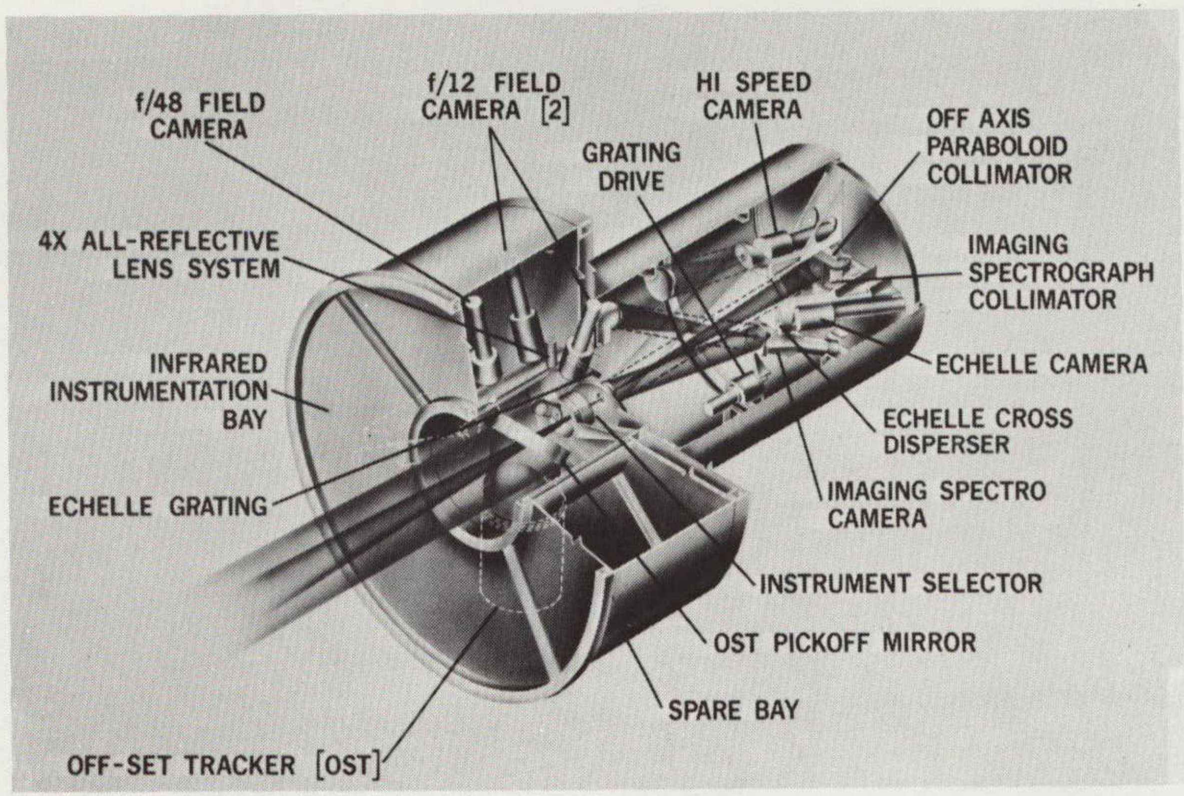
Figure 2-20. Stabilization and Control Subsystem



SUPPLIED BY GSFC

Figure 2-21. LST Astronomical Instrumentation (Typical)

(2) Stow unit.

(3) Extract replacement unit.

(4) Install replacement unit.

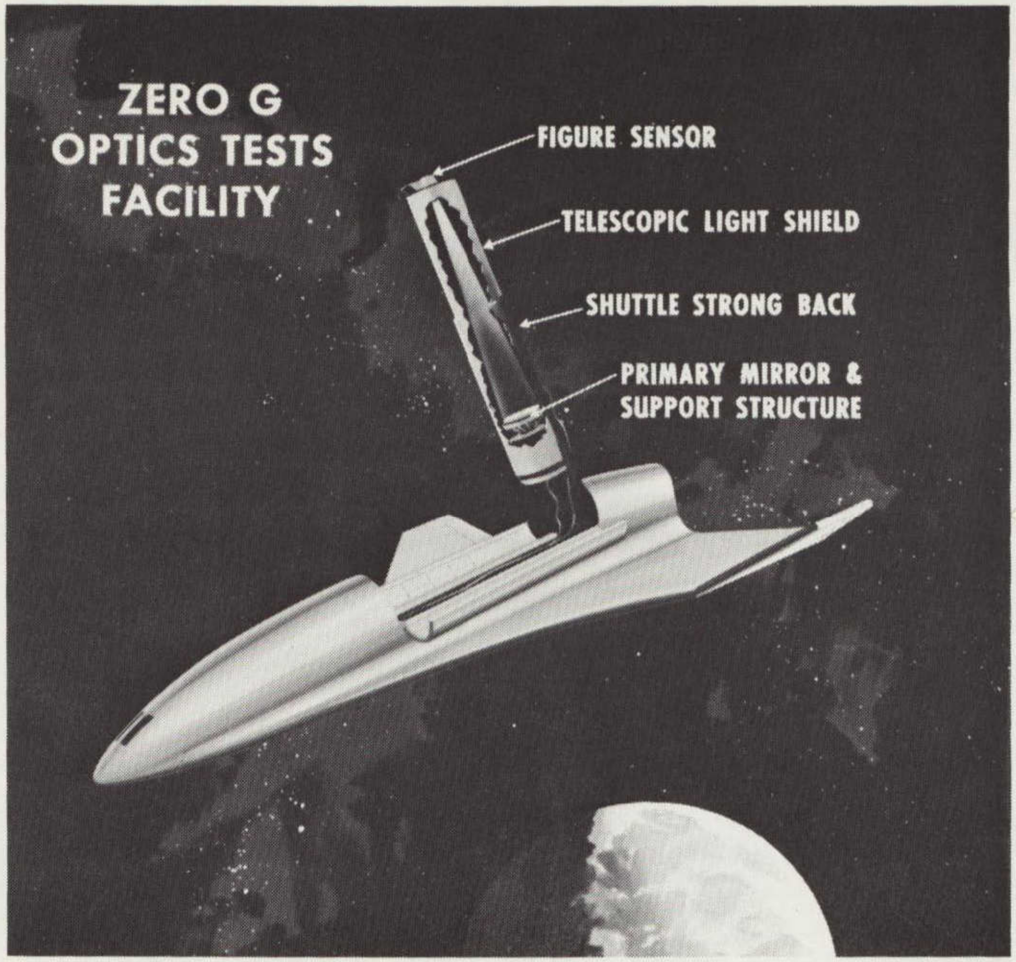
(5) Perform zero g test of primary mirror. As shown in Fig. 2-22, the remote manipulator has the capability to receive the primary mirror in its cell with supporting structure, a telescopic light shield and figure sensor. The strong back deployment structure is extended, carrying the figure sensor to the center of curvature of the mirror and opening the light shield behind it. The shape of the mirror in zero g, as determined in such testing, after manufacture and launch in 1 g, would go far toward early achievement of diffraction-limited performance.

Weight Breakdown of Remote Manipulator

The following weight analyses of the strong back and remote manipulator has been made:

Main Beams	750 Lbs.
Secondary Structure	250 Lbs.
Erection Beams/Cylinder	425 Lbs.
Miscellaneous Supports/Hardware	50 Lbs.
Active Docking Mechanism & Rotary Platform	500 Lbs.
Support Carriage & Drive Docking Support Structure/Mech. Elevator Mechanism Resupply/Service Module Support	400 Lbs.
Launch/Re-entry Support Snubbers Structural Tie/Release	75 Lbs.
	2450 Lbs.

Of the 2450 lb., structure accounts for 1150 lbs. and the remaining 900 lbs. are allocated to controls, actuator cylinders and mechanisms.



SUPPLIED BY GSFC

Figure 2-22. Zero G Optics Tests Facility

3. PROGRAM COSTS AND COST ELEMENT BREAKDOWN

In order to provide realistic cost estimates for the OAO/LST economic analysis, the approach taken was to obtain costs for major program elements from both the data bank and cost estimating relationships of the Central Pricing Group of the GAC contracts department and from the OAO/LEM-based experience of the engineering and manufacturing discipline areas. Due to the wide application of OAO and OAO-type hardware on the OAO/LST, actual OAO component subcontract costs were used as the basis for predicting costs of the LST hardware. Wherever possible, comparable OAO experience costs are presented for LST line item costs.

Costs for GFE equipments, Government facilities, and support manpower were supplied by GSFC via telecon and letter. Titan launch vehicle costs were obtained from the Martin Corporation publication, "Payload User's Guide" and verified by GSFC.

3.1 PROGRAM COST ELEMENTS

As per GSFC request, the cost elements were displayed as shown in Tables 3-1 and 3-2, and form the basis for subsequent accumulation into broader categories for presentation purposes. OAO experience costs were obtained from the GAC/OAO Program Office Contracts Group and from GSFC-supplied information.

The LST design baseline against which these costs were estimated is described in Section 2, together with assumptions and groundrules used in making these estimates.

Cost element line items appearing in Table 3-1 were accumulated to derive the total contractor price for the spacecraft. Table 3-2 lists government costs, including GFE hardware items.

The columns headed "Shuttle Unique" costs include those additional costs necessary to make the Titan baseline design compatible with the Shuttle launch and resupply operations.

3.2 HARDWARE COMPONENT COSTS

The component lists shown in Tables 3-3 through 3-7 were obtained from the GSFC-supplied LST baseline design, through meetings with GSFC personnel, and descriptive material provided. Item costs were estimated with the assistance of the OAO contracts group and project

Table 3-1. OAO/LST Cost Elements (Dollars in Thousands)

COST ELEMENT[4]	OAO EXPERIENCE[1]: [2]DEVEL THRU A-2 LAUNCH	OAO EXPERIENCE[1]: REPEAT FLT (OAO-C) COST	LST - DESIGN BASELINE: DEVEL THRU PROTO FLIGHT	LST - DESIGN BASELINE: REPEAT FLIGHT[5] COST (TITAN)	SHUTTLE UNIQUE COSTS: 1st UNIT	SHUTTLE UNIQUE COSTS: RECURRING
SYSTEM DESIGN (TEST/INTEG/OPS)						
- System Design Engr'g	11,900	1,000	23,765	1,032		
- Project Mgmt	8,200	2,028	4,246	1,514		
- Structure LST (Incl Sec Mech) (6)	12,200	6,414	23,492	8,626	[3]4,797	[3]1,357
- Thermal (Purchased Parts/Mat'l) (6)	Included in Struct. Above		1,644	1,241		
- S/C Mech (Sec Mirr Adj/Rad Select) (6)			6,190	1,234		
- Test & Support Equipment (GSE)	8,900	1,220	7,254	924		
- Subsystem Test Stand	4,000		1,246		110	
- Devel. Test (Manpower)	9,500		849		98	
- Flight S/C Integ & C/O (Contr)	2,500	1,477	1,338	955		
- S/C Support Team at GSFC & KSC	2,250	3,700	2,742	2,482		
- S/C Operations Team (2 Yrs)	1,500	1,826	2,016	1,826		
- Ground Station (Hdw & Software)	Included in GSE Above		8,086			
STAB. & CONTROL SUBSYSTEM						
- System Contract		1,854	3,248	2,938		
- Hardware Contract		3,020	5,376	4,088		
Total	63.7 M					
PNEUMATICS SUBSYSTEM						
- System Contract	Included in S & C Above		873	790		
- Hardware Contract			380	246		
Total						
CDHS SUBSYSTEM						
- System Contract		1,613	1,082	980		
- Hardware Contract		3,900	6,767	3,677		
Total	28 M					
ELECT. POWER SUBSYSTEM						
- System Contract		1,100	1,026	927		
- Hardware Contract		1,436	2,390	1,838		
- Solar Arrays		840	3,300	2,800		
Total	14 M					
- Facilities (at Contractors)			2,011	1,618		
- Titan Interstage (6)	Included in Struct. Above		1,577	628		
- Structure						
Total Contractor Price	166,950	31,428	110,898	40,364	5,005	1,357

Notes:

1. No GFE Included
2. Includes Prototype A-2 A-1, B-S/C (stopped), and B-Recovery of Hardware.
3. Additional Costs for module replaceability. (Guide and Latching Mech, etc.)
4. Cost elements include Qual Assur, G & A, Fee, and Materials Handling Charges spread proportionately on appropriate items.
5. 90% learning curve applied to recurring cost of 1st unit (Protoflight) to obtain 2nd unit cost.
6. Consider as part of structure subsystem.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 3-2. OAO/LST Cost Elements (Dollars in Thousands)

COST ELEMENT	OAO EXPERIENCE: DEVEL THRU A-2 LAUNCH	OAO EXPERIENCE: REPEAT FLT (OAO-C) COST	LST - DESIGN BASELINE: DEVEL THRU PROTO FLIGHT	LST - DESIGN BASELINE: REPEAT FLIGHT COST (TITAN)	SHUTTLE UNIQUE COSTS: 1st UNIT	SHUTTLE UNIQUE COSTS: RECURRING
GSFC COSTS						
1 - Project Management	(Included in line 9, below)		3,500	3,000		
2 - Facility Modifications			8,800			
3 - Exp Test GSE			2,000	1,000		
4 - Telescope - (Optics)			6,200	2,900		
5 - Telescope - (Structure)	23,840	15,000	11,530	3,130		
6 - Offset Tracker			3,520	750		
7 - Radial Insts			4,000	3,000		
8 - On-Axis Inst			14,000	10,000		
9 - T & E Division	14,785	8,868	5,500	4,500		
10 - GSFC Support			3,000	2,500		
11 - OCC Hardware	8,300	2,660	2,000			
12 - OCC Software			3,500	2,500		
13 - Track & Data System (OTDS)	(6,130)	(2,452)	(5,000)	(3,000)		
Total (Above)			67,550	33,280	33,280	33,280
OTHER COSTS						
- Launch Vehicles Titan			22,500	22,500		
- Resupply Platform (1st Unit Cost)					24,850	
- Shuttle (Operational Cost)					5,000	5,000
Total GSFC and Other			90,050	55,780	63,130	38,280
TOTALS/Flight			200,948	96,144		

Table 3-3. Communications and Data Handling Cost Elements

DESCRIPTION	QUANTITY (NOMINAL)	RECURRING	NON-RECURRING	TOTAL (NOMINAL QUANTITY)	QUANTITY (MINIMUM)
Diplexer (OAO)	1	$ 20,000	$ 100,000	$ 120,000	1
Command Recvr (OAO)	1	$ 110,000		$ 110,000	1
Narrow Band XMTR (OAO)	1	$ 30,000	$ 8,500	$ 38,500	1
Command Decoder	2	$ 31,500	$ 3,500	$ 35,000	2
Telem Format Control	1	$ 45,000	$ 5,000	$ 50,000	1
On-Board Processor (OAO)	1	$2,085,000	$1,315,000	$3,400,000	1
Comp Oper Monitor	1	$ 20,000		$ 20,000	1
Narrow Band Tape Rec	1	$ 125,000		$ 125,000	1
Wide Band Tape Rec	2	$ 225,000	$ 500,000	$ 725,000	1
Wide Band XMTR (S-Band)	2	$ 150,000	$ 17,000	$ 167,000	1
Pwr Ampl & RF Sw	1	$ 10,000	$ 20,000	$ 30,000	1
Wiring Harness	1	$ 5,000	$ 15,000	$ 20,000	1
Multiplexer	2	$ 13,500	$ 1,500	$ 15,000	1
Pwr Converter (Digital)	2	$ 30,000		$ 30,000	2
Hybrid Junction (VHF)	1	$ 10,000		$ 10,000	1
Hybrid Junction (S-Band)	1	$ 10,000	$ 20,000	$ 30,000	1
TOTALS:		$2,920,000	$2,005,500	$4,925,500	

NOTE: Minimum Cost Package eliminates unessential redundancy

Table 3-4. Stabilization and Control Cost Elements

DESCRIPTION	QUANTITY (NOMINAL)	RECURRING	NON-RECURRING	TOTAL (NOMINAL QUANTITY)	QUANTITY (MINIMUM)
Fixed Head Tracker	2	$ 110,000	$ 5,000	$ 115,000	1
Dig. Sun Sensor Elect.	1	$ 25,000		$ 25,000	0
Inert. Ref Unit & Elect.	2	$1,500,000		$1,500,000	2
FWJC Controller	3	$ 500,000	$ 250,000	$ 750,000	3
Magnetometer (OAO)	2	$ 30,000		$ 30,000	1
Wheels (Scaled Up OAO)	6	$ 600,000	$ 250,000	$ 850,000	3
Inverter	2	$ 270,000	$ 200,000	$ 470,000	2
Dig. Sun Sensor	4	$ 32,000		$ 32,000	0
Remote Decoder	2	$ 31,500	$ 3,500	$ 35,000	2
Multiplexer	4	$ 27,000	$ 3,000	$ 30,000	2
Wiring Harness	1	$ 5,000	$ 15,000	$ 20,000	1
Magnetom Elect. (OAO)	2	$ 25,000		$ 25,000	1
Solar Aspect Sensor (OAO) RAPS Eyes	4	$ 20,000		$ 20,000	4
SAS Electronics	1	$ 15,000		$ 15,000	1
Mus. Signal Processor	1	$ 15,000		$ 15,000	1
TOTALS:		$3,205,500	$ 726,500	$3,932,000	

NOTE: Minimum Cost Package eliminates unessential redundancy

Table 3-5. Pneumatics Cost Elements

DESCRIPTION	QUANTITY	RECURRING	NON-RECURRING	TOTAL
Gas Tanks (OAO)	3	$ 18,000	$ 9,000	$ 27,000
Regulator (OAO)	2	$ 20,000		$ 20,000
Valve Shut-Off (OAO)	3	$ 39,000		$ 39,000
Piping	1	$ 10,000		$ 10,000
Wiring Harness	1	$ 1,500	$ 5,000	$ 6,500
Pneumatic Conn's	12	$ 25,000		$ 25,000
Fill & Dump System	1	$ 1,500	$ 500	$ 2,000
Solenoid Valve (OAO)	16	$ 64,000		$ 64,000
Gas Jets (Nozzles) (OAO)		$ 10,000		$ 10,000
TOTALS:		$ 189,000	$ 14,500	$ 203,500

NOTE: All components essential for spacecraft survival

Table 3-6. Electrical Power Cost Elements

DESCRIPTION	QUANTITY (NOMINAL)	RECURRING	NON-RECURRING	TOTAL (NOMINAL QUANTITY)	MINIMUM QUANTITY
Batteries (OAO)	6	$ 720,000		$ 720,000	6
Batt Chg Control	6	$ 600,000	$ 150,000	$ 750,000	6
Multiplexer	2	$ 13,500	$ 1,500	$ 15,000	1
Diode Box (OAO)	1	$ 30,000		$ 30,000	1
Pwr Dist Unit	1	$ 15,000		$ 15,000	1
Cmnd Decoder	2				1
TOTALS:		$1,378,500	$ 151,500	$1,530,000	

NOTE: Solar Cells, see Table 3-1

Minimum Quantity required for spacecraft survival

Table 3-7. Electrical and Wiring Cost Elements

DESCRIPTION	QUANTITY	RECURRING	NON-RECURRING	TOTAL
Fusistor & Pyro		$ 1,500		$ 1,500
Struct Heaters		$ 1,200		$ 1,200
Antenna S-Band	2	$ 25,000	$ 75,000	$ 100,000
Antenna VHF	2	$ 25,000	$ 75,000	$ 100,000
TOTALS:		$ 52,700	$ 150,000	$ 202,700

NOTE: All components required for spacecraft survival

personnel. The package costs shown here do not include the cost of the subsystem module structures. These are covered in the structural estimate, Table 3-1. Subsystem design, test and production costs for the completed modules are also shown in Table 3-1. It should be noted that the Offset Tracker, a major cost item and the only significantly new hardware development required for the LST fine pointing and stabilization, is not included in the Stabilization and Control Subsystem Module but is a separate, GFE module associated with the Scientific Experiment Instrumentation and Telescope costs. This is in keeping with OAO program experience in which the fine error signal for OAO spacecraft pointing is derived from the Goddard Experiment Package and the Princeton Experiment Package in OAO's B and C, respectively.

Another major hardware cost item is the Secondary Mirror Adjustment mechanism, whose purpose is to maintain the optical alignment and focus of the primary and secondary mirror combination despite the relative displacements caused by thermal and mechanical environmental changes. The cost of this mechanism was supplied by GSFC and accumulated under the line item of S/C mechanisms, Table 3-1.

Replaceable subsystem module costs were estimated on the basis of present OAO state of technology and, as discussed in Section 4, represent specific fixed points on the subsystem vs. MTTF cost curves. These project the costs of increased redundancy and extending technology to achieve greater MTTF values.

Tables 3-3 through 3-7 are also used to obtain the costs of the minimum redundancy package by eliminating all but essential equipment redundancy for spacecraft survival. However, since no specific attempt was made at this time to incorporate an independent, low-cost backup set of components, a minimal savings resulted from this approach. A more comprehensive analysis of subsystem level of redundancy vs. cost optimization is recommended for future effort in this area.

3.3 EXPERIMENT AND PRIMARY OPTICS COSTS

3.3.1 Experiments

A breakdown of experiment costs relative to flyable spacecraft is shown here. This reflects the fact that experiments can very well be completely different instruments from mission to mission, and in any event would be substantially changed so that some development costs would be involved for each.

	Prototype Flight Art.	2nd Flight Art.	3rd Flight Art.
On-Axis Exp Pkg	\$14 M	\$10 M	\$10 M
Radial Exp Pkgs (3)	\$ 4	\$ 3	\$ 3
Total Exp Cost	\$18 M	\$13 M	\$13 M

3.3.2 Primary Optics

These are very long lead time items, especially the primary mirror. Thus to protect the program schedule, one more set of optics will be manufactured than the number of vehicles. In this way a failure of the prototype optics in manufacture or transport, for example, would be covered by the available back-up set. If not used for the prototype, the back-up would be available to cover a failure in the optics of a succeeding vehicle.

	Primary Mirror	Secondary Mirror	Offset Tracker Flat
Prototype Flt Art.	\$2.2 M	\$.65 M	\$.45 M
Spare (Back-Up) Set	\$2.0 M	\$.50 M	\$.40 M
2nd Flt Art.	\$2.0 M	\$.50 M	\$.40 M
3rd Flt Art.	\$2.0 M	\$.50 M	\$.40 M

3.3.3 Radial Experiment Selector

This is a mission-success mechanism which inserts a diagonal flat mirror into the primary optical path to divert the light to the radial experiments. The mirror is capable of rotation to switch the light to a selected experiment. However, when on-axis experimentation is to be resumed, the mirror must be retracted from the primary optical path. If the mechanism fails to do this, the on-axis experiment is disabled.

The mechanism will be assumed attached to the on-axis package, and therefore replaceable with the on-axis experiment. As such, the selector falls in Group 2 Reliability category. Cost is estimated as \$.50 M for prototype and \$.36 M for 2nd and 3rd Flight Articles.

3.3.4 Offset Tracker

This is a mission-success sensor which is incorporated in one of the four radial bay modules and is replaceable in orbit. The function of this sensor is to generate the spacecraft fine pointing error signal using the guide star light diverted from the primary optical system by the 45°, offset tracker flat. Cost is estimated as \$3.52 M for the prototype, and \$0.74 M for 2nd and 3rd Flight Articles.

3.4 SUBSYSTEM COST SUMMARY

Table 3-8 presents the summation of the cost elements into the categories listed. It should be noted that certain major cost items (telescope structure, offset tracker, and experiment instrumentation) are categorized under GSFC costs and do not appear in the subsystem cost comparison of Table 3-9. When comparing OAO experience and LST design baseline cost estimates, it should be remembered that, with the exception of the structure, the LST systems are essentially the same type hardware (and same state of technology) that has been developed on the OAO program and is available today as flight qualified hardware. In contrast, the major load-bearing portions of the LST structure have been specified as fabricated from Titanium with the total structural weight being approximately 11,000 lbs.

3.5 TOTAL PROGRAM COST SUMMARY

The total OAO/LST program cost summary is presented in Table 3-9 in the format requested by GSFC so as to provide a comparison of the 6-Flight Titan-launched program with the 3-flight Shuttle-launched program. The Shuttle-launched program includes a first flight on Titan, 3 additional service and instrument package update Shuttle flights, and the development cost of the automated servicing module.

Table 3-8. Subsystem Cost Comparison - OAO Vs. LST (Dollars in Thousands)

	OAO EXPERIENCE		LST DESIGN BASELINE	
COST ELEMENT	DEVEL. THRU A-2 LAUNCH	REPEAT FLT. COST	DEVEL. THRU PROTO. FLT.	REPEAT FLT. COST
System Design, Test, Ops.	48,750	11,251	53,553	10,351
Structure Subsystem	12,200	6,414	32,903	11,729
Stab. & Control Subsystem	63,700	4,874	8,624	7,026
Pneumatics Subsystem	Included in S & C		1,253	1,036
Comm. & Data Handling Subsystem	28,000	5,513	7,849	4,657
Electrical Power Subsystem	14,300	3,376	6,716	5,565
Total Contr. Price	166,950	31,428	110,898	40,364

Table 3-9. Total OAO/LST Program Summary (Dollars in Thousands)

6 FLIGHT - WITHOUT SHUTTLE		SHUTTLE PROGRAM	
Proto Flight		Proto Flight (Titan L/V)	
Contr. - 110,898		Contr. - 115,903	
Gov't. - 67,550		Gov't. - 67,550	
Launch - 22,500		Launch - 22,500	
	200,948		205,953
2nd. Flight		2nd. Flight (Shuttle L/V)	
Contr. - 40,364		Contr. - 41,721	
Gov't. - 33,280		Gov't. - 33,280	
Launch - 22,500		Launch - 29,850	
	96,144		104,851
3rd. Thru 6th. Flight		3rd. Flight (Shuttle L/V)	
Contr. - 143,500		Contr. - 39,200	
Gov't. - 108,200		Gov't. - 31,000	
Launch - 90,000		Launch - 5,000	
	341,7000		75,200
Total Program		Total Program	
Contr. - 284,762		Contr. - 196,824	
Gov't. - 209,030		Gov't. - 131,830	
Launch - 135,000		Launch - 57,350	386,004
	638,792	3 Inst.	
		Update - 54,000	54,000
			440,004

It should be noted that in both cases the prototype flight includes the non-recurring development costs as well as the cost of the first flight article and that the costs of succeeding flight articles are reduced on a 90% learning curve.

Table 3-10 presents the same information in comparison with costs for the OAO flight spacecraft.

Table 3-10. Program Cost Comparison (Dollars in Thousands)

OAO	6 LST - WITHOUT SHUTTLE	3 LST - SHUTTLE
Through Second Flight S/C - 213,875	Proto Flight S/C - 178,448	Proto Flight S/C - 183,453
3rd Flight S/C - 83,251	2nd Flight S/C - 73,644	2nd Flight S/C - 75,001
4th Flight S/C - 57,956	3rd Flight S/C - 69,300	3rd Flight S/C - 70,200
	4th Thru 6th Flight - 182,400	3 Sets Instr - 39,000
Prog Total (Less Launch) - 354,082	Prog Total (Less Launch) - 503,792	Prog Total (Less Launch) - 367,654

3.6 COMPARISON WITH OAO COST EXPERIENCE

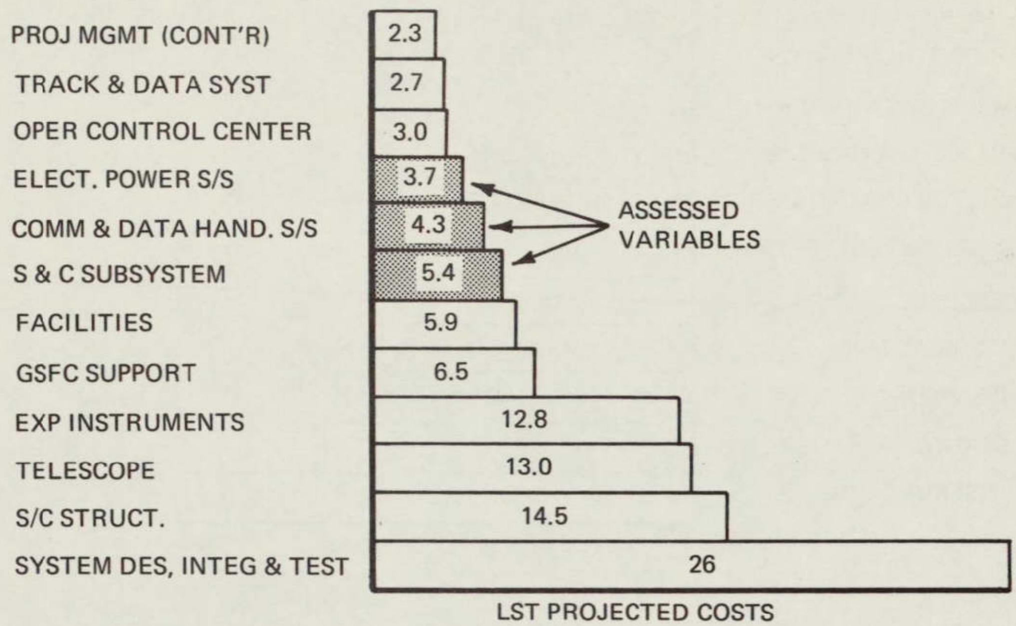
Tables 3-1, 3-2, 3-8 and 3-10 provide comparative costs for OAO, LST-Titan, and LST-Shuttle cost elements and flight spacecraft.

Figures 3-1a, b and 3-2a, b show graphically the relative importance of the major cost elements for LST development and recurring flight spacecraft in comparison with similar OAO program cost elements. Most apparent in this comparison is the shift in relative cost between the stabilization and control subsystem, which was the most costly single element during OAO development, and the spacecraft structure. This, together with the telescope becomes the most costly element of the LST development program.

Since much of the OAO Stabilization and Control subsystem hardware is applicable to the LST mission, the extensive component development, analysis and test required for OAO stabilization functions need not be repeated. The capability to replace subsystem modules in orbit provides the program flexibility of using prototype equipment for early flights and updating by shuttle resupply, thus eliminating the risk of system failure or serious degradation and permitting reduction in both component redundancy and development test.

On the other hand, the LST structure as described in Section 2 is significantly different in both concept and requirements from the OAO structure. While the resupply mode permits a reduction in requirements for the replaceable modules, the major structural items must provide mechanical integrity through ground testing, Titan launch, and years of orbital operation. It should be noted, however, that fabrication of the structure entirely from aluminum, rather than the extensive use of titanium presently specified, would result in a considerable cost savings. An average cost-complexity factor of 2-4 can be applied to titanium fabrication as compared with conventional aluminum fabrication costs.

Annual program costs for the OAO/LST Baseline program without Shuttle and comparable annual costs for OAO program experience are presented in Figures 3-3 and 3-4. It should be noted that the peak expenditures for the projected OAO/LST program do not significantly exceed those of the on going OAO program.



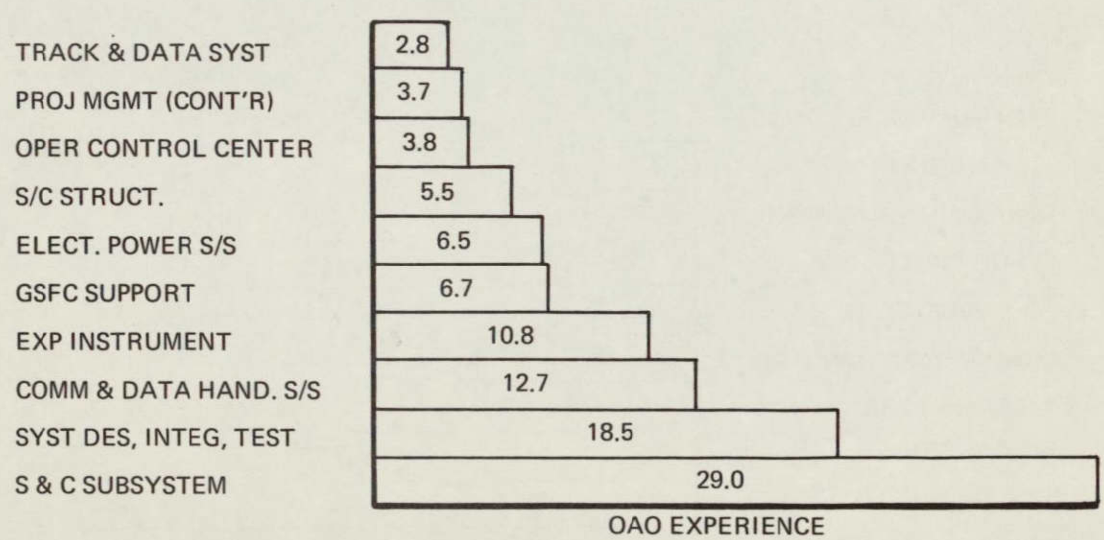
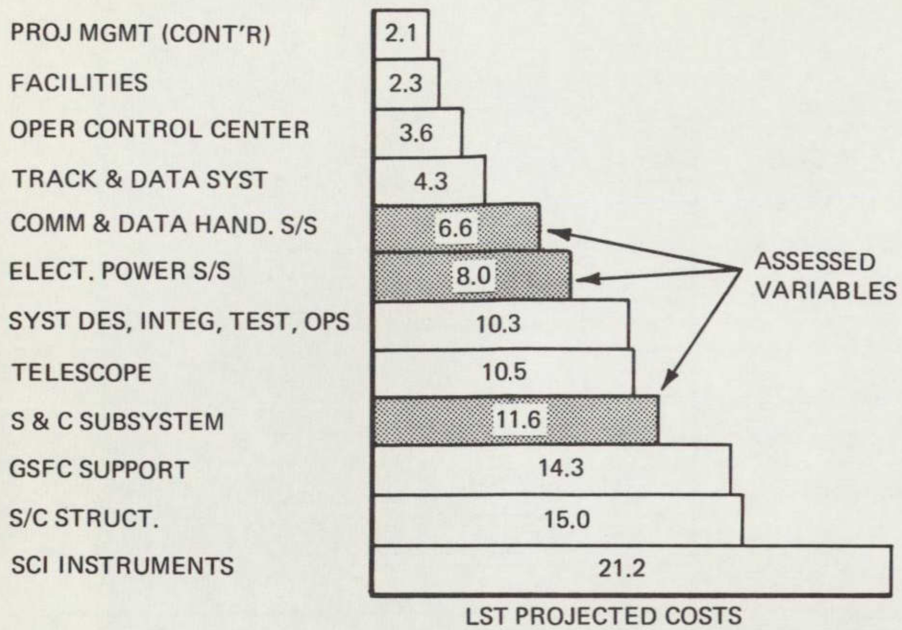


Figure 3-1. Development Cost Comparison
(Percent of Total Development, Including Prototype)



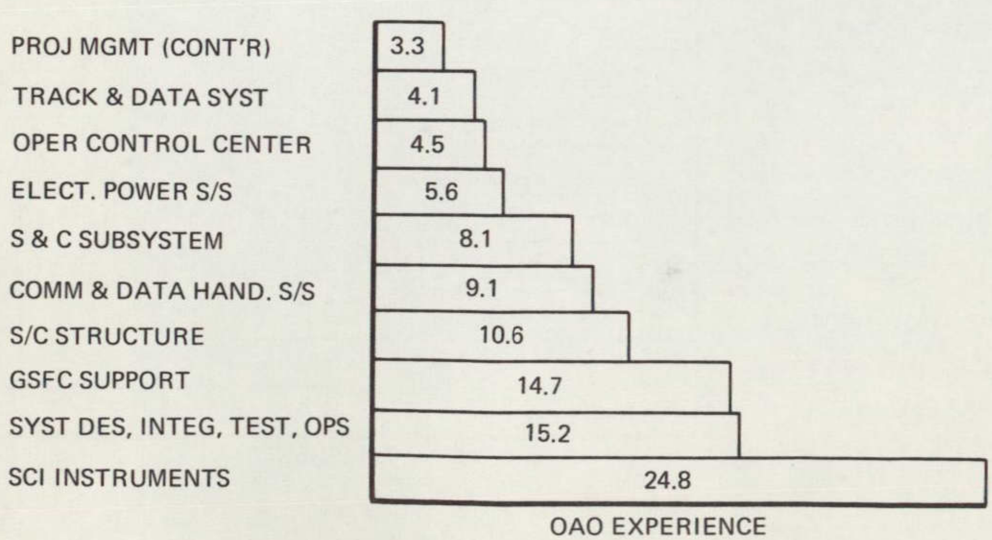


Figure 3-2. Recurring Flight Unit Cost Comparison
(Percent of Total Spacecraft Costs)

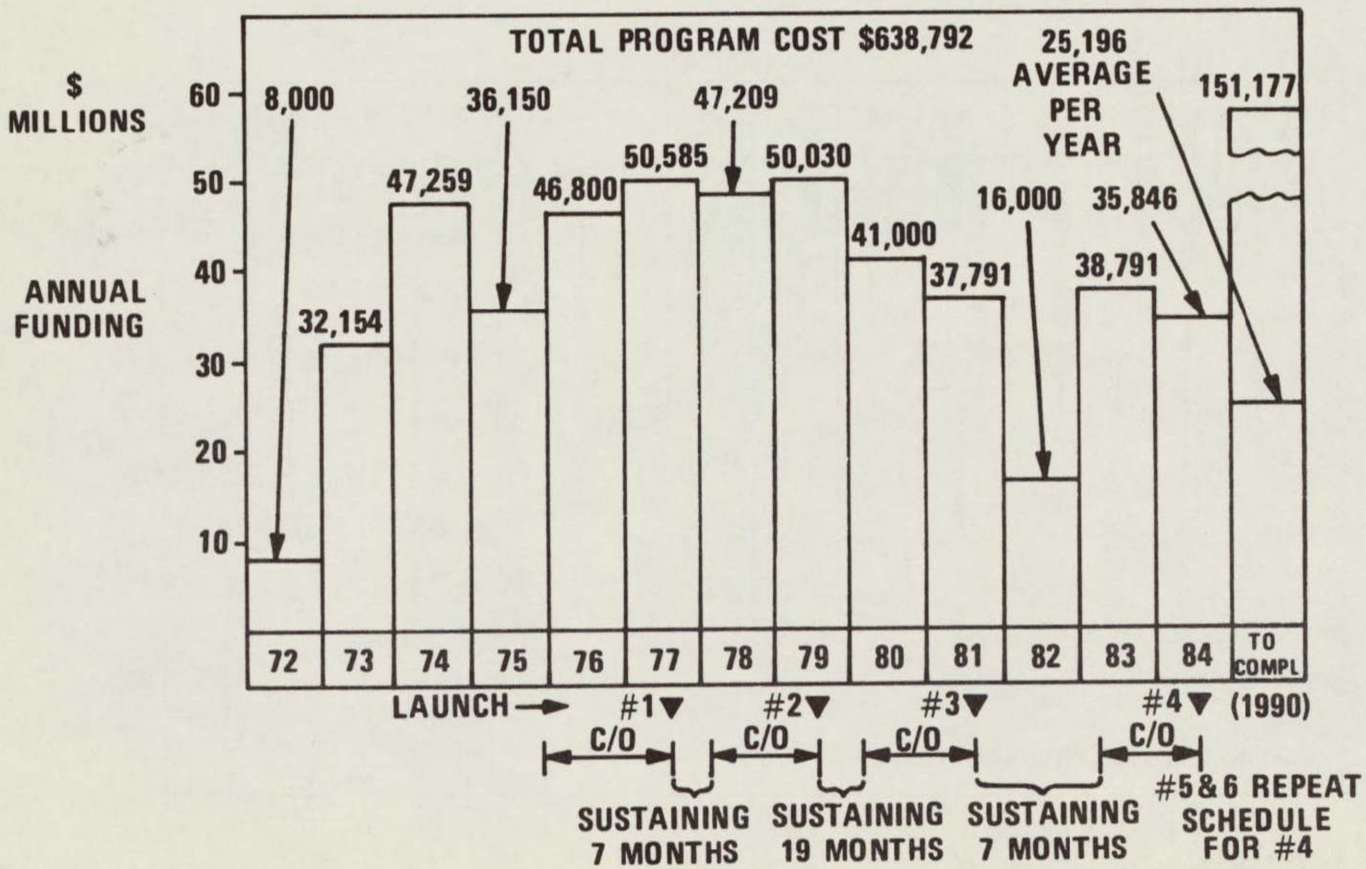


Figure 3-3. OAO/LST Baseline Program Cost/Without Shuttle

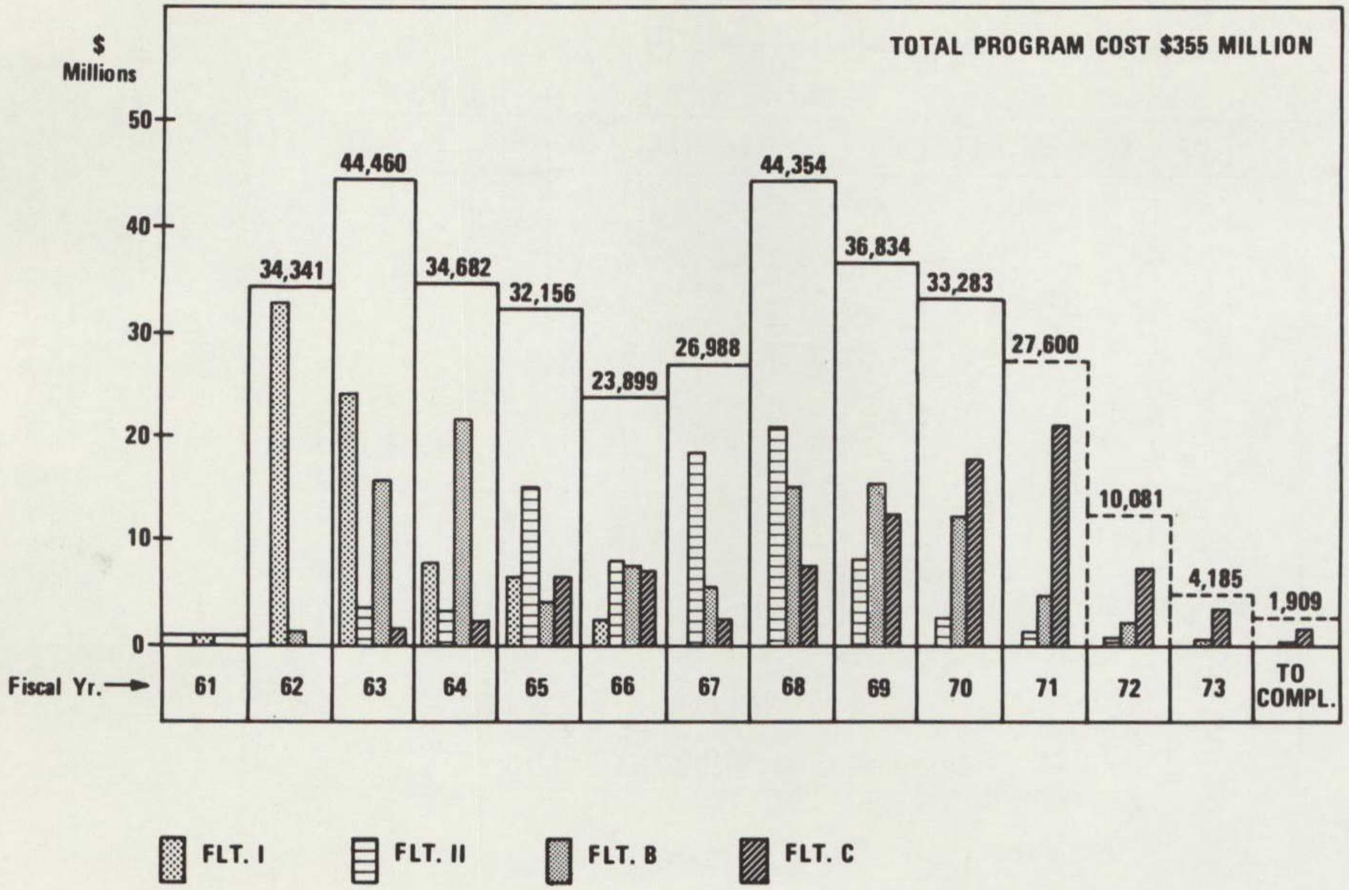


Figure 3-4. OAO Annual Program Costs

4. METHOD OF ANALYSIS FOR OAO/LST SHUTTLE PROGRAMS

4.1 SUMMARY OF METHODOLOGY

Cost in the OAO/LST program is generated as: Nonrecurring development and hardware, recurring cost per flight, and steady state operating cost. Each of these areas are, in turn, subdivided into cost items sensitive in varying degrees to over-all system characteristics called cost drivers. These cost drivers, through their influence on operational and design costs, will, as they vary, cause major fluctuations in the over-all program cost of the OAO/LST. The cost impact analysis problem then becomes one of describing the interrelationships of cost drivers and program characteristics, and then committing these interrelationships to an analytic method capable of exercising them and outputting the results in terms of system performance and cost. In this way will cost drivers and their impact on the program be related. Analysis of these results leads to conclusions on optimum cost driver values and the definition of an optimum system point design. A flow diagram of this process is presented in Fig. 4-1.

4.2 RELIABILITY AND MAINTAINABILITY

The following reliability/maintainability oriented cost driving relationships were developed for this study:

- The relationship between MTTF and cost
- The relationship between resupply interval, uptime ratio, MTTF and cost.

The establishment of these relationships required the performance of mission, system, and design analyses. These analyses were completed with the use of computer programs and modeling tools which had been developed as part of the GAC reliability/maintainability space advanced development effort. The computer programs and modeling tools were:

- <u>Multi-state effectiveness model (MARKAP)</u>

  Markov models which evaluate the probability of being in various system states.

- <u>Availability Apportionment Model (APPOR)</u>

  Calculates the availability (uptime ratio) from MTTF values for each combination of shuttle resupply frequency, and delay time.

  Distributes availability goals (uptime ratio goals) on a system level down to the subsystem and subsystem functional level taking into account the differing design factors of each item.

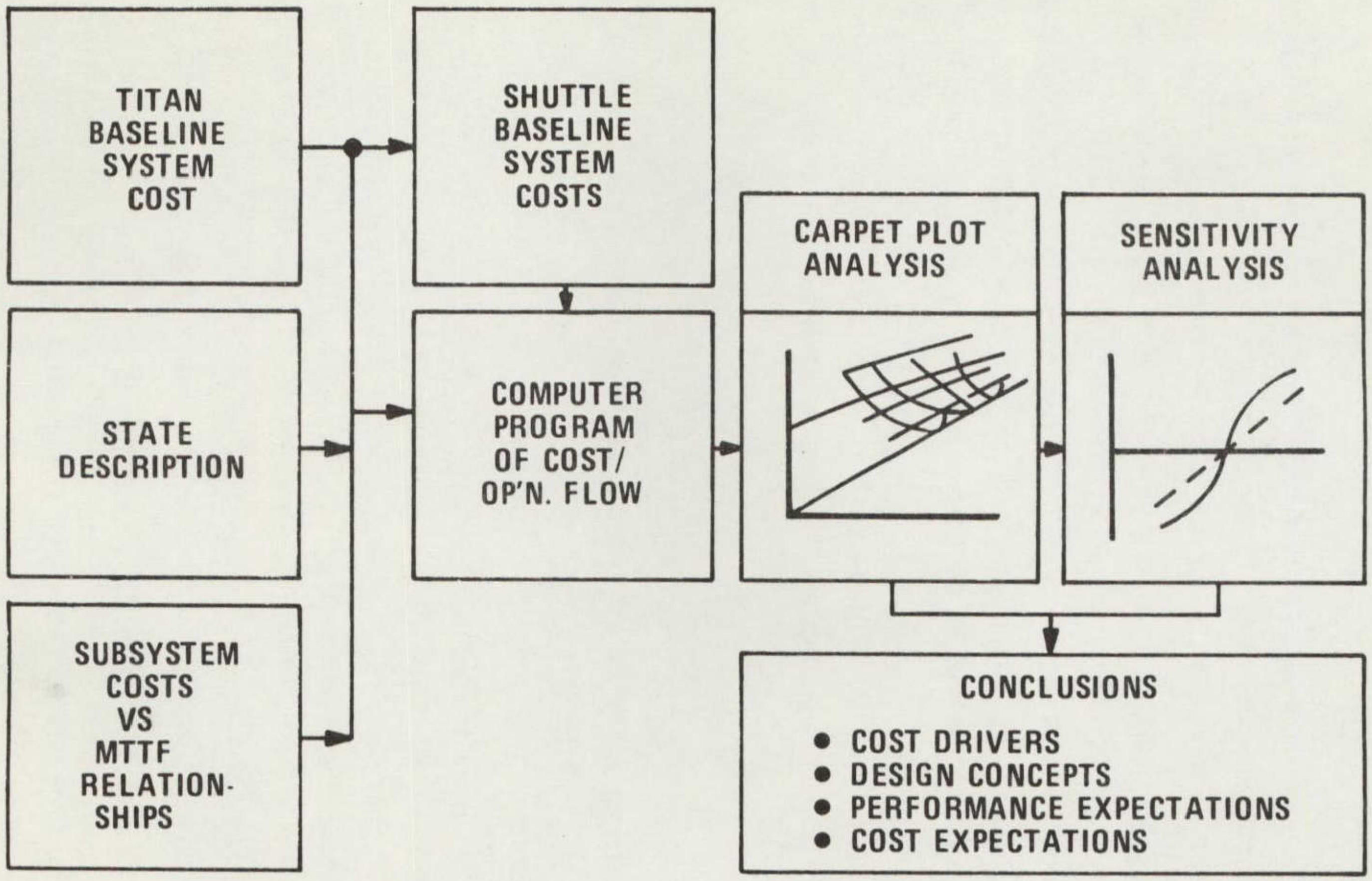


Figure 4-1. OAO/LST Shuttle Economic Analysis Technique

These programs and aids were utilized to perform the following specific tasks.

- Mission requirements analyses
- System analyses
- Subsystem and subsystem function availability apportionment.

4.2.1 Reliability/Maintainability Cost Driver Analysis

The R/M tasks completed for this study represented a comprehensive analysis of the R/M measures which affect the LST economics. These tasks identified which measures were cost drivers, and provided a credible analytical base upon which LST cost vs. program effectiveness tradeoffs could be performed.

4.2.2 Mission Requirements Analyses

Group definition and group composition, the subtasks from which mission requirements analyses are composed, required an analysis of the LST hardware which was replaceable, redundant, necessary for the success of the LST mission, necessary for the full performance of the LST mission, and/or necessary for the survival or resupply of the LST vehicle. Thus the following groups of hardware were defined for the LST vehicle and mission:

- Group 1: Nonreplaceable, Nonredundant Mission Success Group

  Equipment considered essential for mission success which has no redundancy.
- Group 2: Replaceable Redundant Mission Success Group

  Equipment considered essential for mission success which is redundant.
- Group 3: Replaceable Redundant Mission Degradation Group

  Equipment which is considered to be necessary for full mission performance, but whose loss is not considered to be the loss of mission success. This group is redundant.
- Group 4: Survival and Docking Group

  Equipment which is considered essential for the performance of docking or to prevent catastrophic failure. Catastrophic failure is considered to be a failure which renders the LST useless for the mission under consideration.

Once the group definition subtask was completed the specific hardware which composed each group was determined.

4.2.3 System Analyses

4.2.3.1 Data Collection

The collection of MTTF Data was the first subtask accomplished as part of the system analysis task. This collection was carried out on three levels: (1) OAO, (2) LM, and

(3) AIRCRAFT. The data utilized were actual flight data whenever possible for the same hardware or similar hardware. When flight data was not available data estimates made on previous programs were used. In the absence of both of the above, engineering judgement was used to generate selected data.

The result of this subtask was MTTF data or data estimates on every piece of LST hardware for all three design levels.

4.2.3.2 State Definition

- Shuttle

  The analysis of LST alternatives required that the system interaction be described by system conditions or states and transitions between these system states. These system states are generated by a subset of the set of all possible failure and repair combinations of the system. For the purpose of this study ten (10) states of the LST system have been defined.

  State 1 - All equipment up.
  State 2 - Failure of nonreplaceable redundant equipment.
  State 3 - Failure of replaceable redundant equipment.
  State 4 - 2 out of 3 radial experiments up.
  State 5 - 1 out of 3 radial experiments up.
  State 6 - No radial experiments up. (Group 3)
  State 7 - Survival Group up. (Group 4)
  State 8 - Group 2 and survival group up.
  State 9 - Repair via shuttle.
  State 10 - Catastrophic failure.

- Titan

  The system states for the Titan LST system are defined to be:

  State 1 - All equipment.
  State 2 - Failure of redundants.
  State 3 - 2 out of 3 radial experiments up.
  State 4 - 1 out of 3 radial experiments up.
  State 5 - No radial experiments up.
  State 6 - Catastrophic failure.

4.2.3.3 Mode Definition

- Shuttle

  The 10 LST states may be combined into four (4) mission modes which describe different levels of LST performance. These four modes and their state composition are given below:

  Mode 1 - Full Performance Mode: ability to carry on all desired experimental activities with the desired accuracy.

  Mode 2 - Degraded Performance Mode: ability to carry on only the on-axis experiment, or the on-axis experiment with one of two experiments with the desired accuracy. (States 4, 5, and 6).

Mode 3 - Survival Mode: loss of experimental success but survival functions still exist allowing for maintenance. (States 7, 8, and 9).

Mode 4 - Catastrophic Failure Mode: loss of spacecraft and the ability to restore it to satisfactory operation. (State 10).

- Titan

The six (6) LST states which are defined for the Titan replacement sequence can be combined into three of the four modes given above. The Titan mission modes are:

Mode 1 - Full Performance (States 1 and 2).

Mode 2 - Degraded Performance (States 3, 4, and 5).

Mode 4 - Catastrophic Failure (State 6).

These states and modes are shown in Figs. 4-2 and 4-3.

4.2.3.4 Group Block Diagrams and Math Models

The LST reliability diagrams were drawn up from the data of three technologies: Aircraft Level, LM Level and OAO Level. Wherever possible, failure rates used were from actual recorded discrepancies of the 3M* run for similar type equipment at the aircraft level. Similarly failure rates were gathered from LM and OAO data. For the items for which there were no data, predicted values and engineering judgment was used to arrive at the failure rates for each equipment. Once the data were gathered, the failure rates and MTTF were calculated for each subsystem for each of the above mentioned technologies. All redundancy was assumed to be standby redundancy. That is, whenever a failure occurs, the redundant unit would be energized and assume the function of the failed equipment.

Figure 4-1A is an example of the actual group block diagrams which are given in detail in enclosure (4) of the Appendix (Vol. II). The figure shows how the group failure rates (λ failures/hr.) were generated as the sum of the individual subsystem failure rates. This summation was carried out for each of the three levels given above. The MTBF (MTTF) given in the figure is the reciprocal of the failure rate (MTTF = $1/\lambda$).

Each of the subsystem blocks given in the figure were developed from subsystem block diagrams where the subsystems contained previously developed hardware. Figure 4-1B is an example of the subsystem block diagrams given in detail in enclosure (4) of the Appendix. The figure shows the Communications and Data Handling subsystem diagram for the OAO

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*Navy field failure data compiled on Maintenance, Material, and Management of naval aircraft for distribution to major Navy contractors.

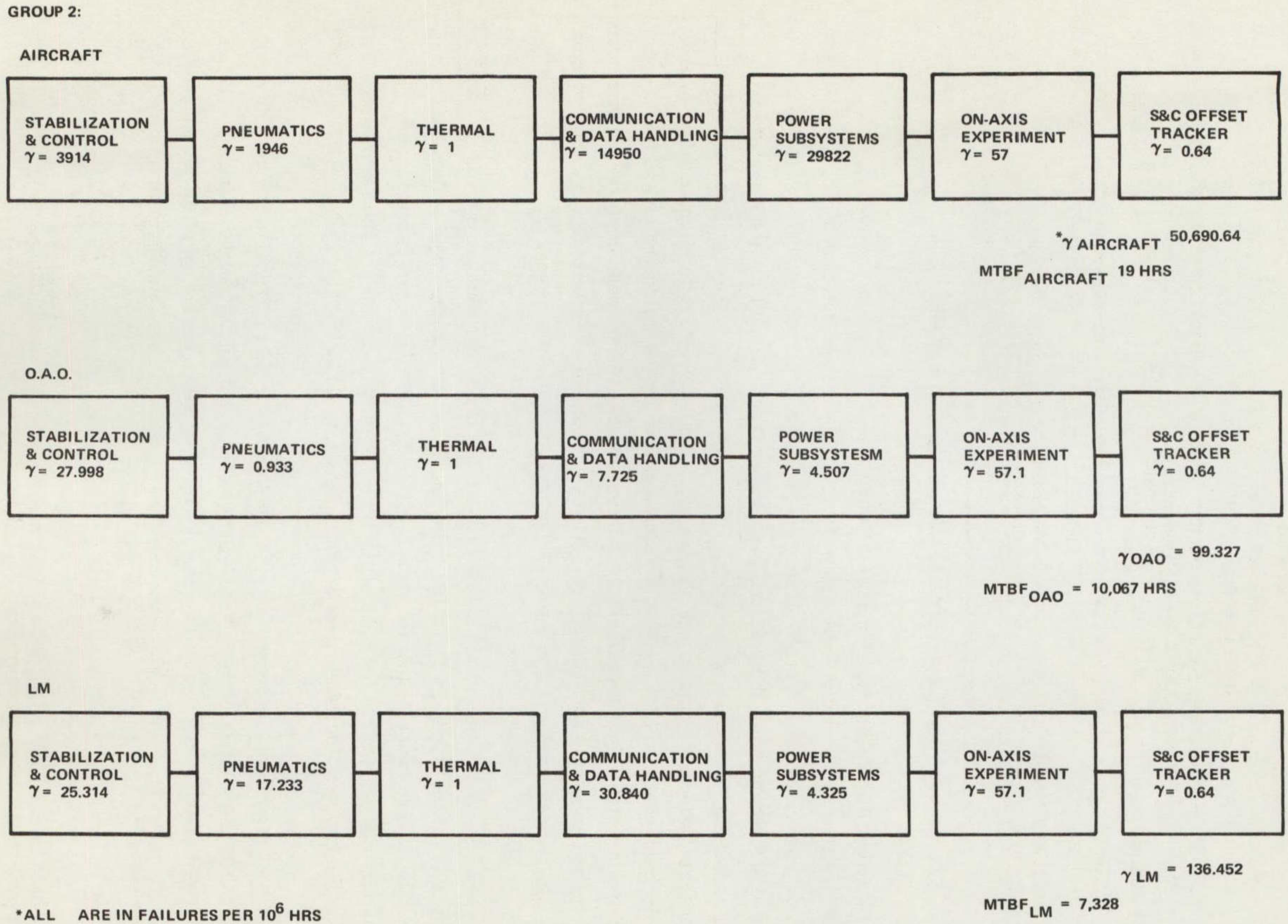

Figure 4-1A. Group Level Failure Rate Analysis

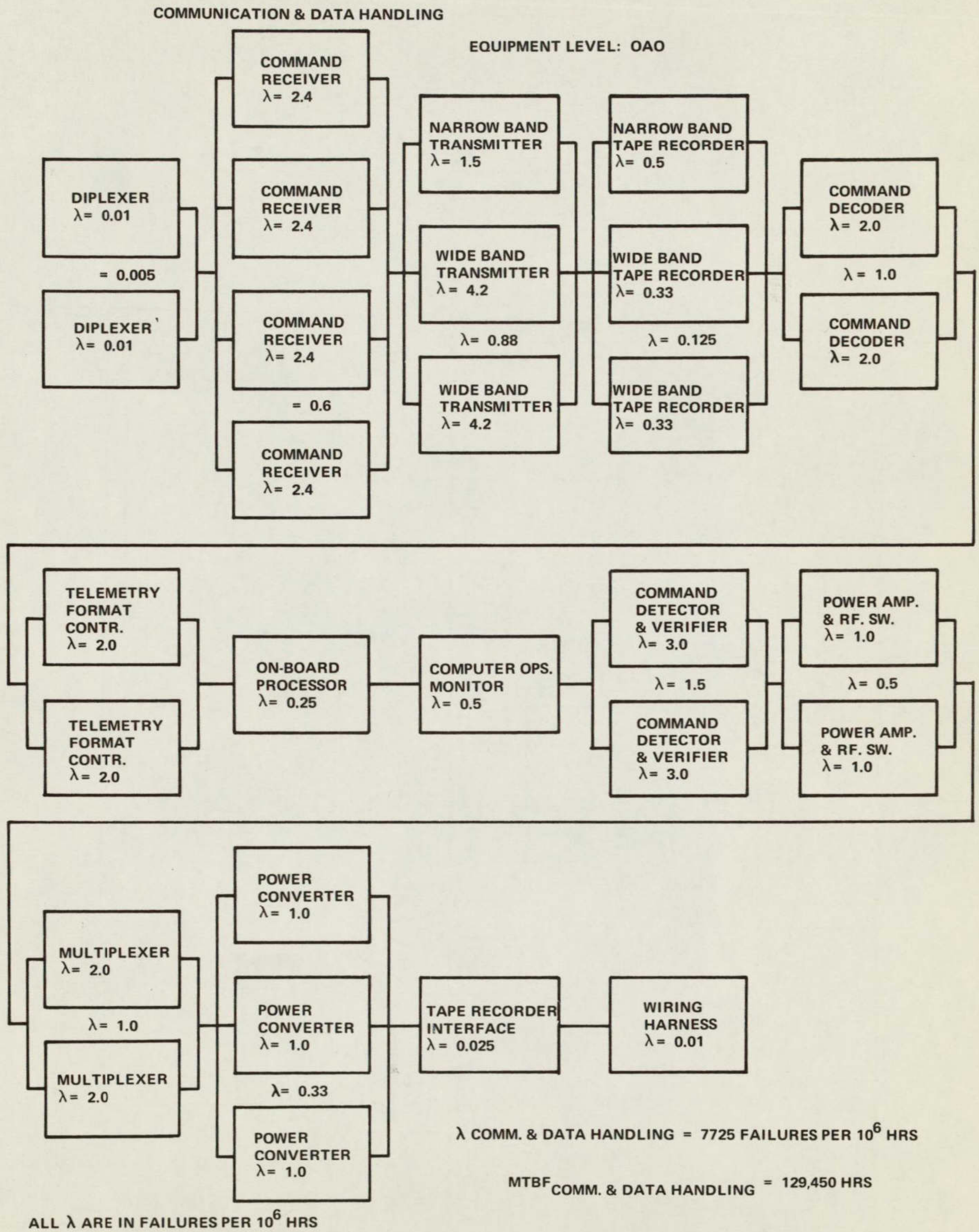

Figure 4-1B. Equipment Level Failure Rate Analysis

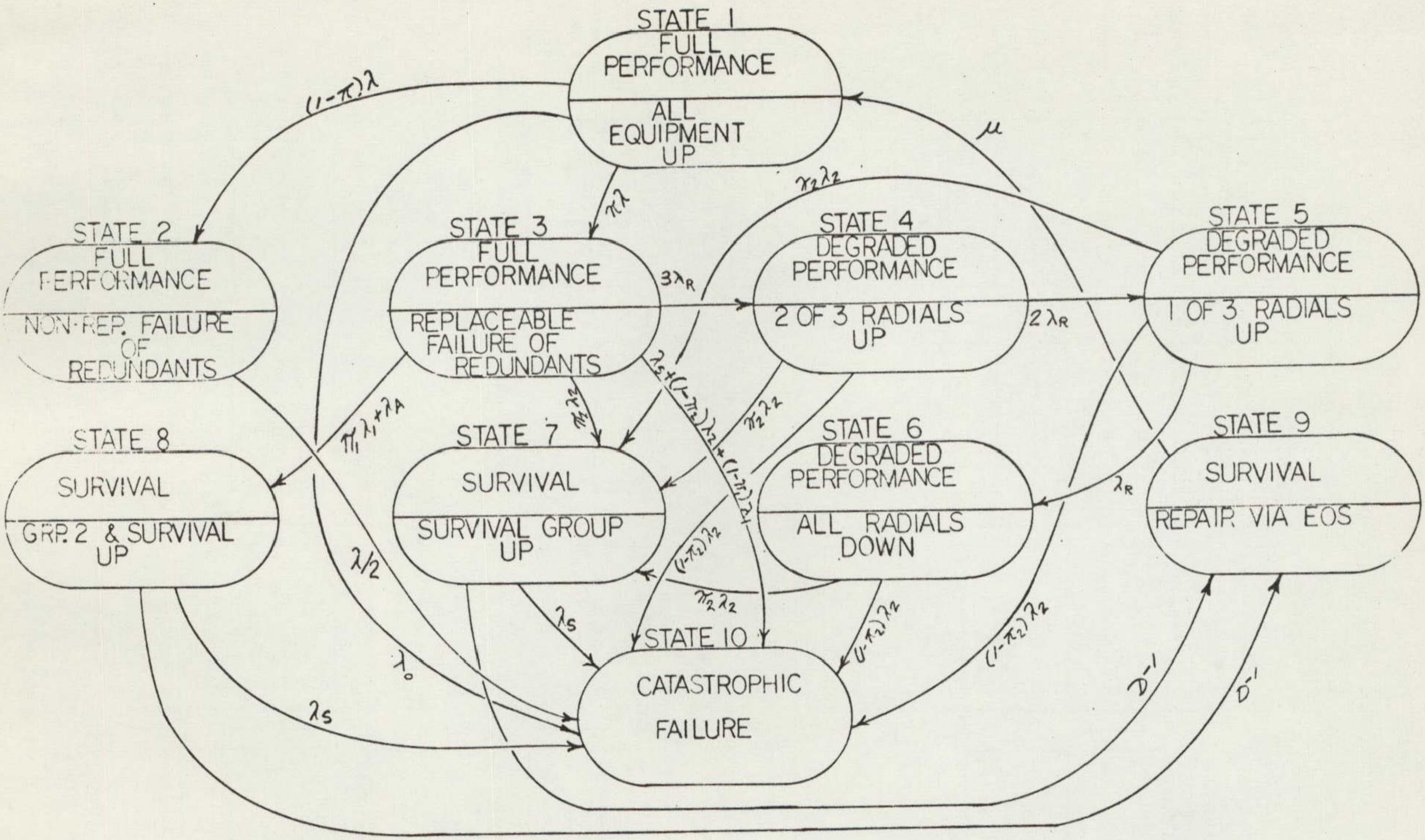

Figure 4-2. OAO/LST State Diagram With Shuttle

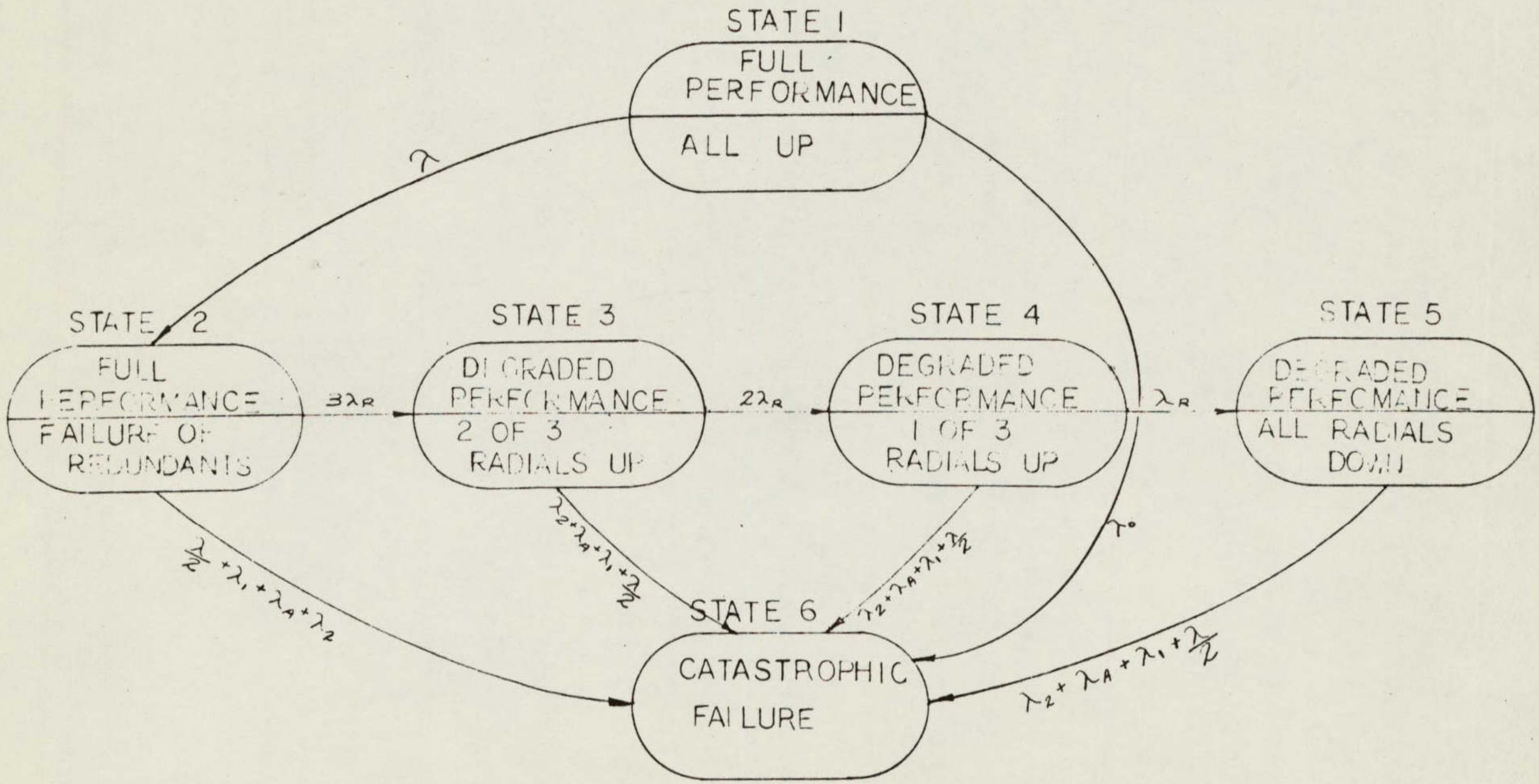

Figure 4-3. OAO/LST State Diagram With Titan

level. The subsystem failure rate was generated by serial-parallel reduction of the hardware failure rates given in the figure, assuming that all redundancy is of the stand-by type. For the stand-by redundancy case, reduction of a serial-parallel system requires the summation of the MTBF's of the parallel elements (since each redundant element in effect increases the life of the "block" of parallel elements by one (1) MTBF), and the summation of the resulting "block" failure rates ($\Sigma_i \lambda_i$ or Σ_i $(1/MTBF_i)$, i = number of blocks) in a manner analogous to serial-parallel reduction of a resistance network. This reduction was carried out on all these levels for all applicable subsystems.

The specific group failure rates obtained from this analysis were utilized as the matrix elements for the input to the MARKAP program. The subsystem and element failure rates were utilized in the development of the cost vs. MTTF relations as given below.

4.2.4 Availability Apportionment

The availability apportionment task is designed to generate data for the R & M Apportionment Program APPOR. The accomplishment of two major tasks are required to develop this data. These tasks are subsystem apportionment, and subsystem functional apportionment.

The availability Apportionment Program (APPOR) is a tool, generated by R & M advanced development, which uses LST MTTF (mean time to failure) goals and shuttle schedule delay times to compute subsystem MTTF apportionments. These MTTF apportionments are used in a cost model, to evaluate overall LST costs. The subsystem apportionments are also used to generate the subsystem functional apportionments by again employing the APPOR program.

The mission requirements analysis and system analysis tasks provide a good insight into the effect changes in the level of failure rate for groups of equipment have on the uptime and availability of the LST system. In order to enhance the credibility of the availability estimates the availability apportionment model independently calculated the availability estimates from the MTTF values for each combination of shuttle resupply frequency and delay time according to the procedure given in Sec. 5. These estimates were then apportioned first to the subsystem level and then to the subsystem function level.

The core of the apportionment model is the technique of using weighting factors to evaluate the relative contribution of each subsystem to total LST system performance in terms of

uptime ratio or MTTF. The following factors were of importance, in varying degrees, to LST hardware:

- Cost
- Nonreplaceability
- Criticality
- Design inflexibility
- Environment
- Design complexity
- Weight.

Each of these factors was assigned a weight to indicate its relative importance, and each LST subsystem was ranked by engineering judgement for each of the factors. The relative contribution of each subsystem was calculated as a linear combination of its judgement values and their respective weighting factors. The apportionments were then made in proportion to the total weight of each subsystem. In this manner a very realistic apportionment is achieved.

Specifically, the LST Apportionment model consists of a main program and two subroutines, with the capability of calling the costing model as a subroutine. The main program APPOR first calls subroutine UPTIME which uses ten candidate LST MTTF goals and seven shuttle schedule delays to calculate and print the expected uptime and uptime ratios for the seventy combinations. The seventy uptime ratios are transferred back to APPOR which apportions each LST uptime ratio to the subsystem level and prints the results. The subsystem MTTF apportionments are then transferred to the LST cost model.

These apportionments enhance the credibility of the LST system uptime ratios since they relate these ratios to actual subsystem functional level MTTF requirements. These requirements provide a crosscheck to the level estimates using the "Top-Down" approach since this approach, which is based on the designer's estimate of the possible achievement of his hardware, indicates the design feasibility of the level estimates.

4.3 COST VERSUS MTTF

Select modules of the LST subsystems considered to be replaceable in orbit were identified at the black box level and their functions categorized. A search was made of in-house historic data, and vendor quotations of cost and MTTF of modules performing similar functions on LM, OAO, and various aircraft programs. Basic data areas utilized in this

analysis are shown in table 4-1. The aircraft programs were further subdivided into military and commercial (707 type) aircraft categories.

Table 4-1. Information Source Areas for Cost Vs. MTTF Analysis

Cost Comparison Modules
Electrical Power
Batteries
Inverters
Regulators, Controls, Distribution
Communication & Data Handling
VHF Transceiver
S-Band Transmitter
Wide Band Transmitter (S-Band)
Command Receiver
Narrow Band Transmitter
Command Decoder
Telemetry Format Control
On Board Data Processor
Multiplexer
Diplexer
Wiring Harness
Data Link
Tape Recorders (wide and narrow band)
Stabilization & Control
Inertial Reference Unit
Inertial Reference Electronics
Sensor Electronics (digital)
Remote Decoder
Signal Processor
Multiplexer
Wiring Harness
Inverter
Pneumatics
Tanks
Solenoids
Regulators

The data obtained was then correlated to provide a best guess for those modules where data was not available for each technology.

The data for each replaceable subsystem was then summed to provide the equivalent cost of subsystems designed to each technology. The module MTTF data was similarly utilized to determine equivalent subsystem MTTF's.

This data was then compiled to indicate the effect of cost variations for each subsystem based on commercial aircraft (707 type), military aircraft (A6A type), OAO, and LM technologies.

The VHF transceiver curve given in Figure 4-5 is based on actual data received from several vendors quoting prices and reporting actual in-use MTTF values at the technological levels indicated.

Typical subsystem MTTF vs. cost curves generated from a composite of functional component data for the communications and data handling, stabilization and control, and electrical power subsystems are shown in Figures 4-6 A, B, and C. The OAO/LST flight article cost vs. MTTF curve shown in Figure 4-7 was generated according to the procedure given pictorially in Figure 4-4. The development of the curve utilized a regression analysis to determine the best fit curve through the cost MTTF data points. It was found that an equation of the form:

$$\text{cost} = \text{cost}_{\text{reference}} \left(\text{MTTF}/\text{MTTF}_{\text{reference}}\right)^{x}$$

was appropriate for all replaceable subsystems, where the value of "x" fell between 1.0 and 1.25. The cost elements from which Figure 4-7 was generated included fixed costs and some costs whose variability was not assessed, as well as the variable cost of the replaceable subsystems.

4.4 SHUTTLE-DESIGN TRADE-OFF

Since the Shuttle, through in-orbit repair, in effect extends satellite lifetime, a methodology is required to describe the trade-off between Shuttle revisit cost and the cost of additional satellite life. Fig. 4-8 has been developed to show this relationship between Shuttle flight

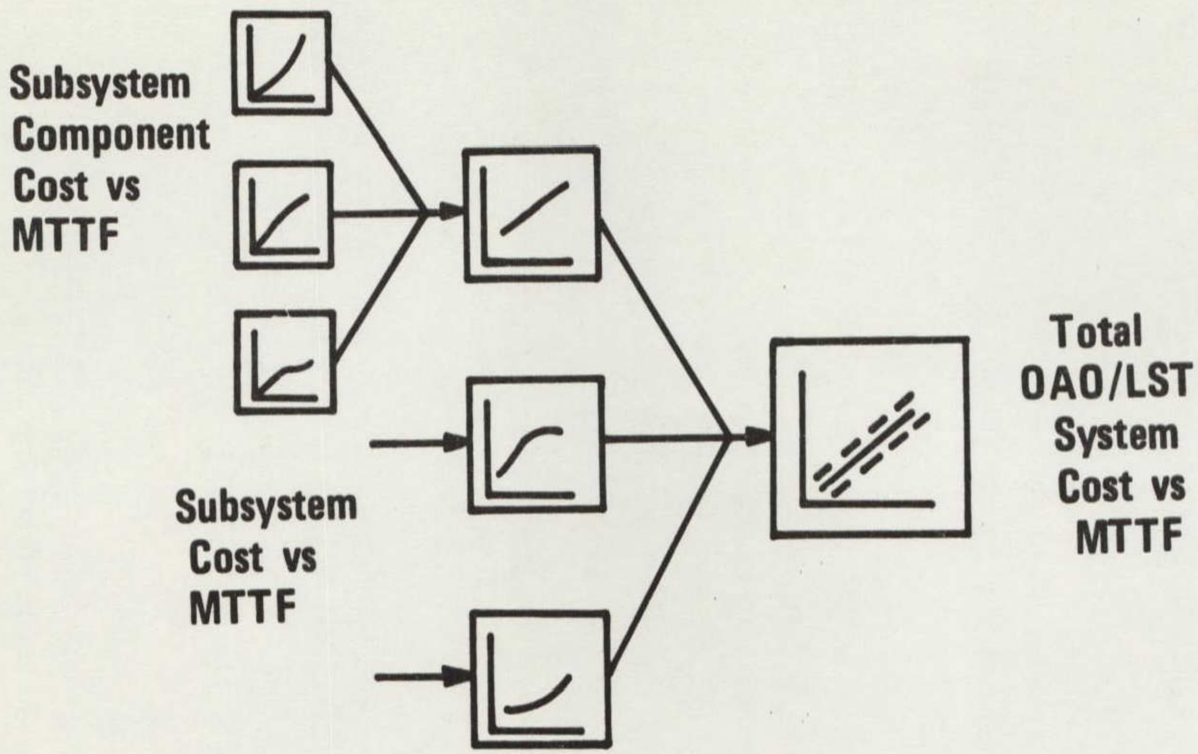

Figure 4-4. OAO/LST Method of Accumulating Cost vs MTTF

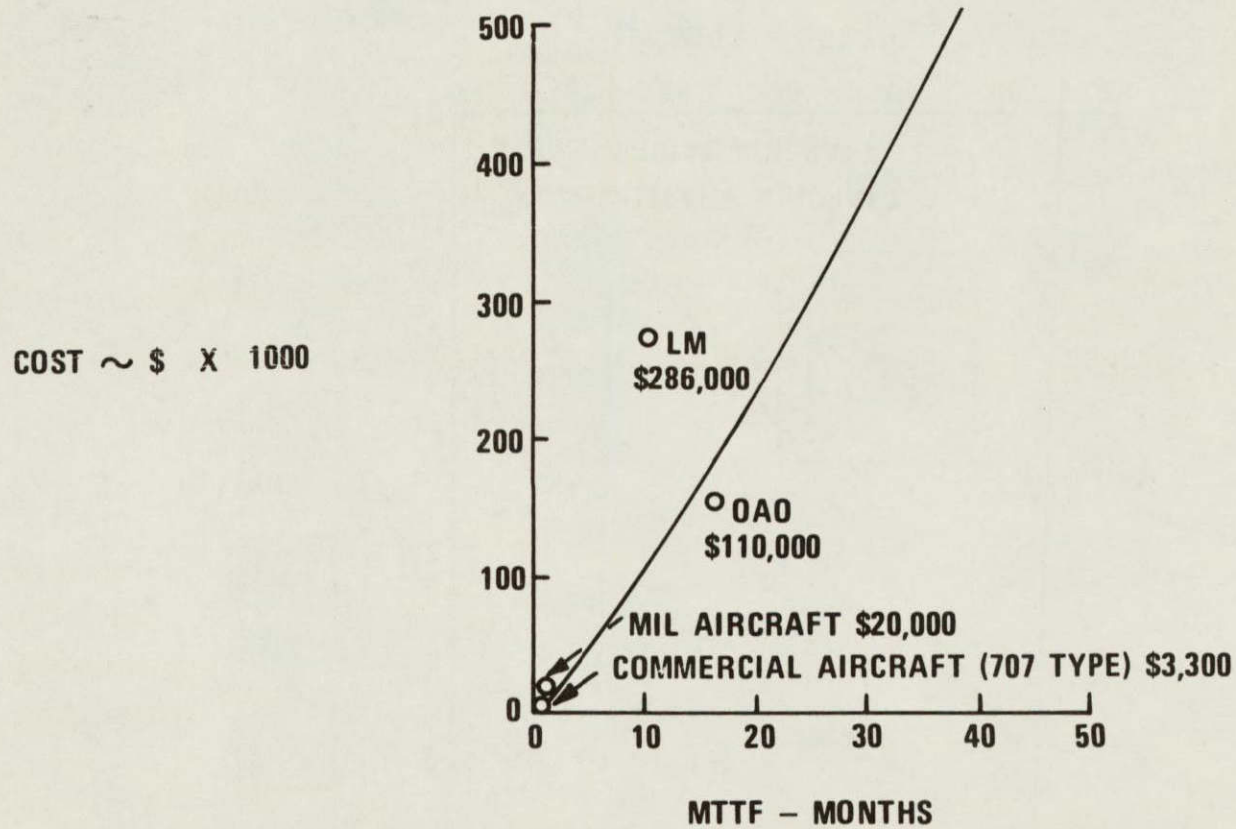

Figure 4-5. VHF Transceiver, OAO/LST Typical Subsystem Component Costs vs MTTF

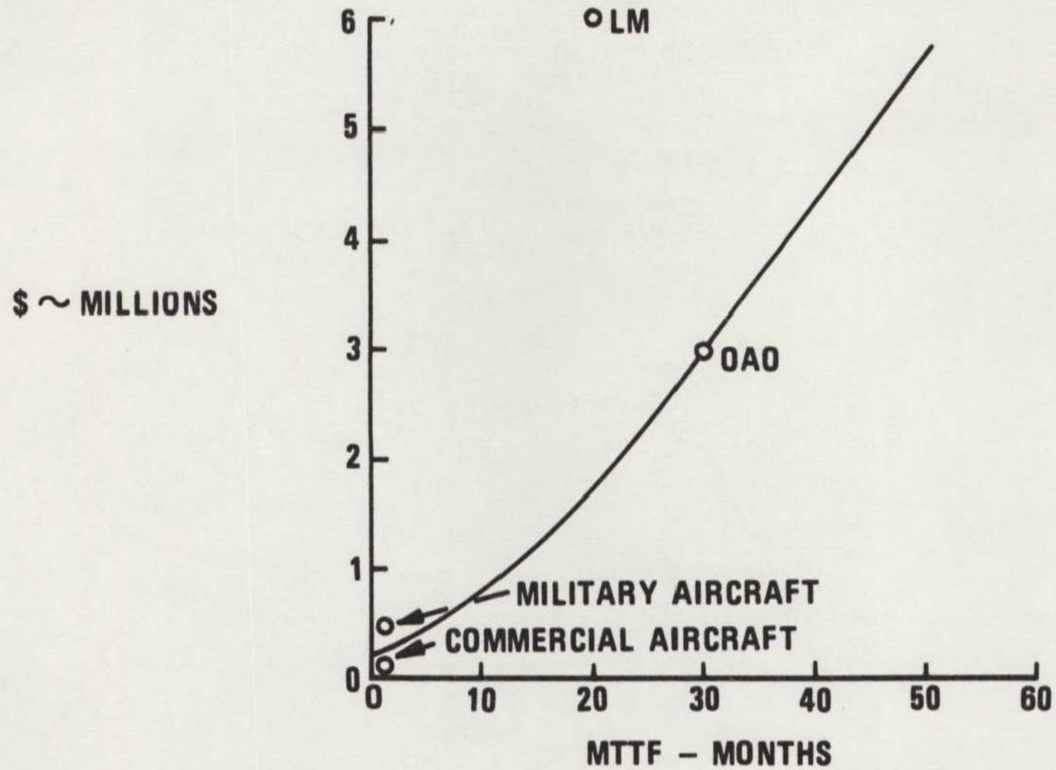

Figure 4-6A. Communication & Data Handling, OAO/LST Subsystem Cost Versus MTTF

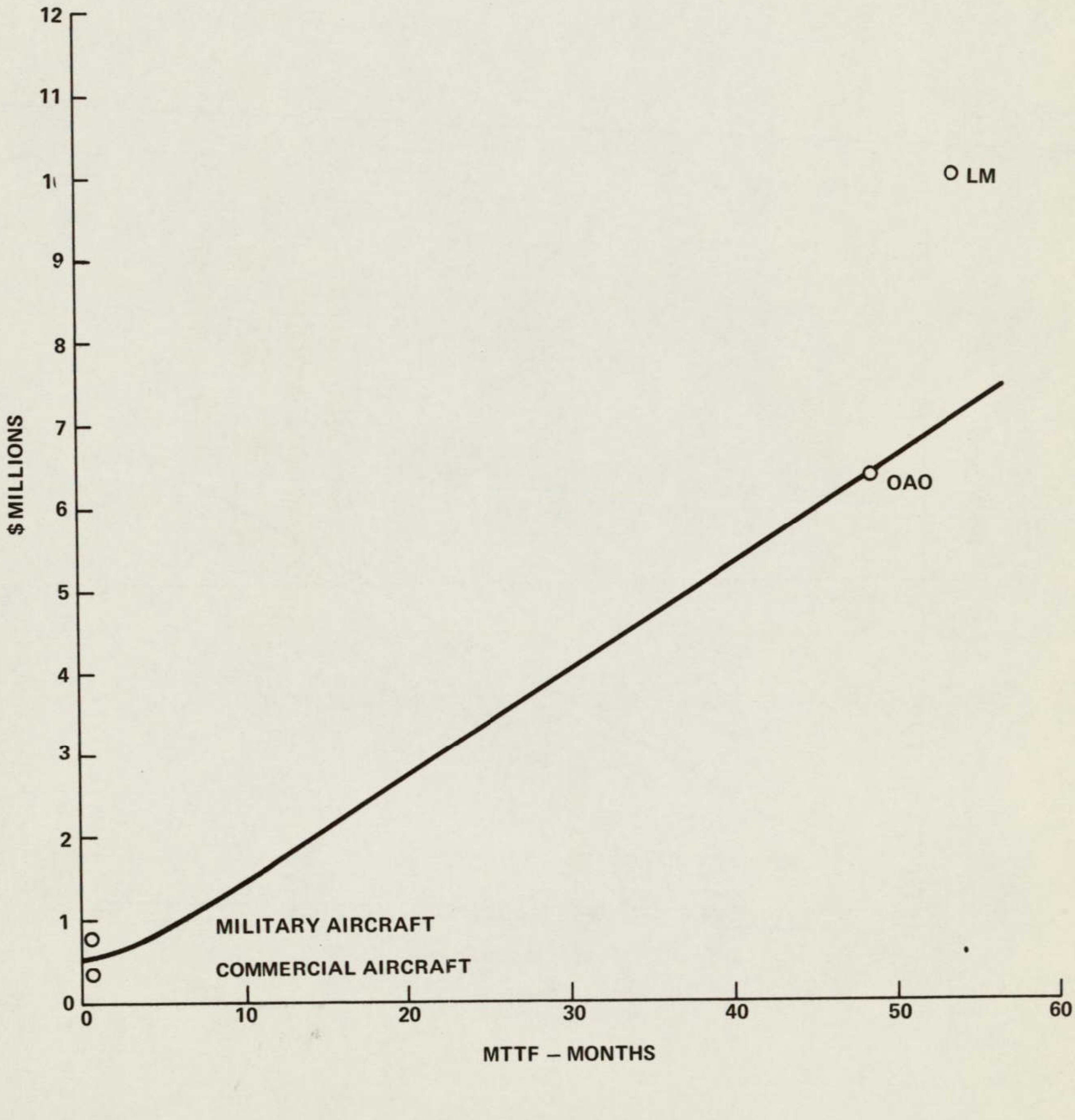

Figure 4-6B. Stabilization & Control, OAO/LST Subsystem Cost vs MTTF

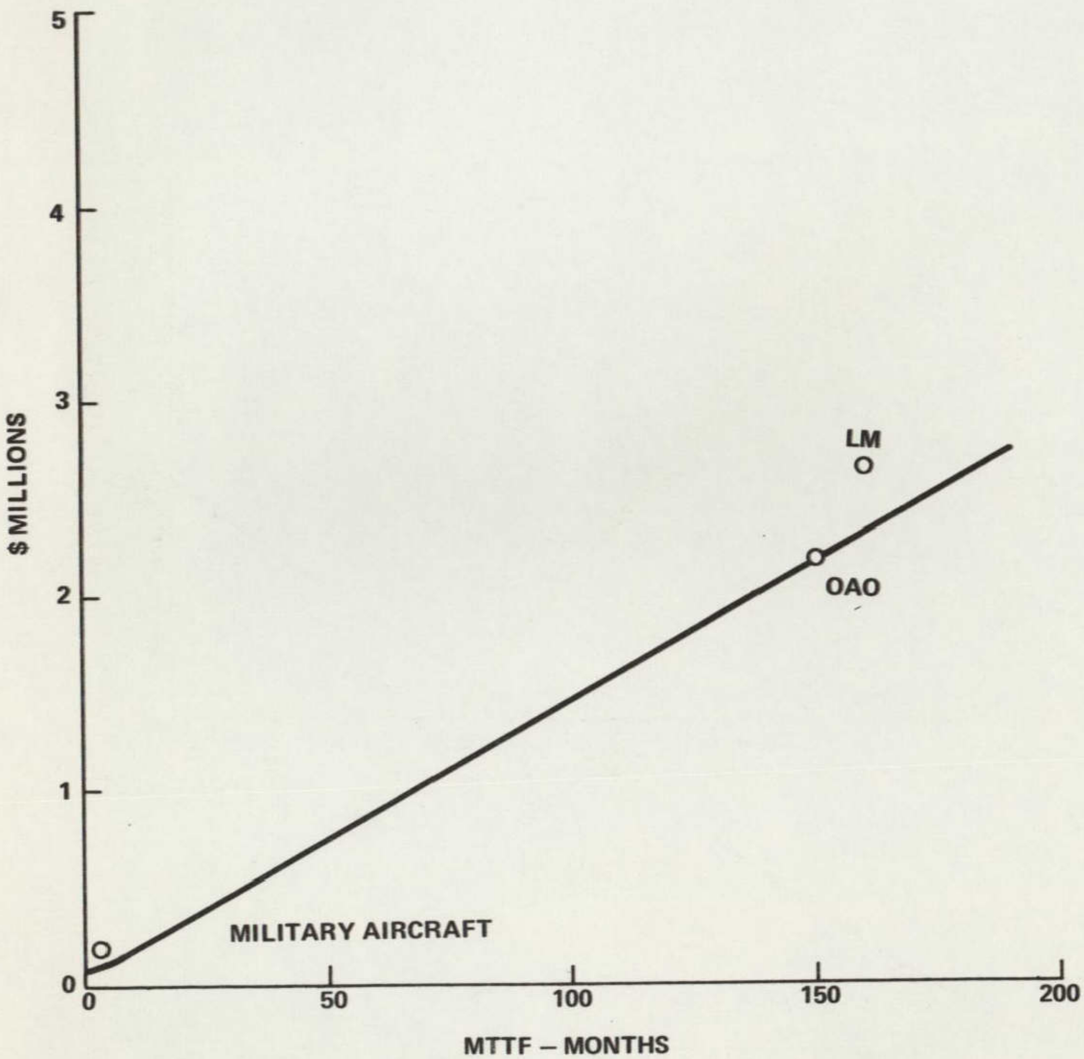

Figure 4-6C. Electric Power, OAO/LST Subsystem Cost vs MTTF

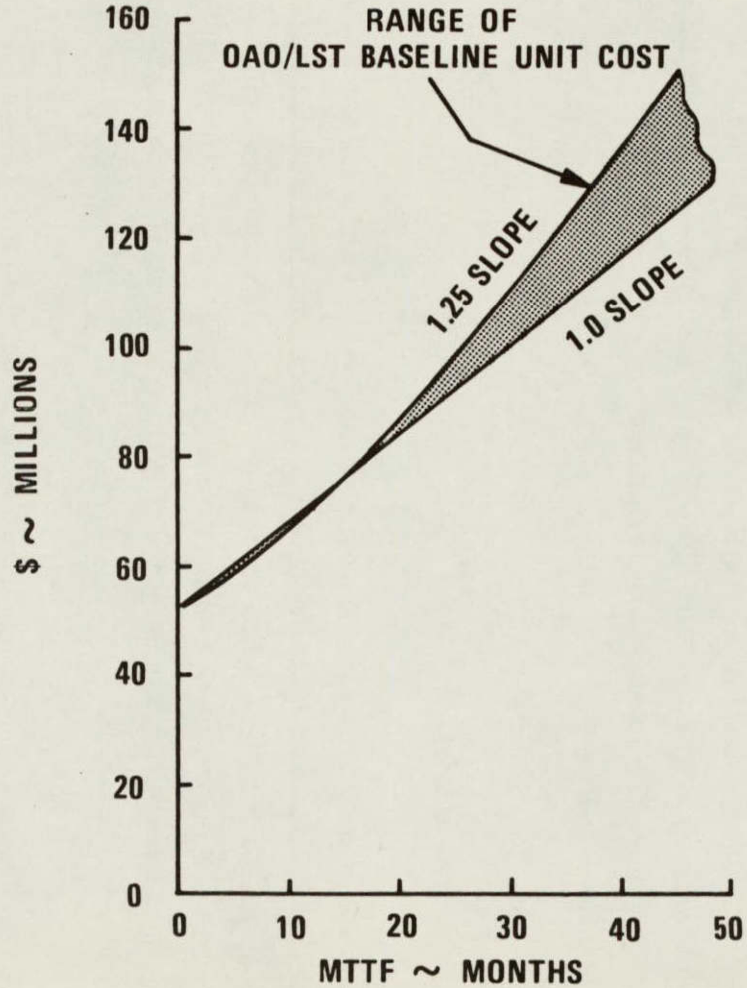

Figure 4-7. OAO/LST Flight Article Cost vs. MTTF

cost and the cost of achieving increased satellite MTTF through improved design. Considering that each Shuttle revisit adds an increment of life equal to (1) MTTF, the cost of a Shuttle flight may then be compared to the cost of adding (1) MTTF through improved design and production. Since this means doubling the MTTF, the cost to double MTTF was taken from the upper set of curves (Fig. 4-8) and plotted, producing the lower set. The addition of various Shuttle flight costs defines levels of MTTF above which use of the Shuttle is economically preferable, and below which improved MTTF through design is best.

4.5 COST/OPERATION COMPUTER PROGRAM

A mathematical model to study performance and cost (PERCOM) was devised to assist in the spacecraft system optimization process. A digital computer program of this model was developed and exercised. This program (PERCOM) relates spacecraft and total program costs with the system performance characteristics of:

- System Repair Delay
- Satellite MTTF
- System Uptime Ratio and Years
- Nominal System Cost

The system repair delay is that span of time elapsing between the occurrence of a failure and its repair. This time may be entirely devoted to readying and launching expendable or re-usable boosters, or it may be taken up in part by administrative procedures and equipment testing and readying. For system performance analysis purposes, repair delay is considered as dead time during which the satellite is in a survival mode and is not performing any experimental activities.

Satellite MTTF is the mean or average life expectancy between the achievement of operation and the occurrence of a failure requiring repair. If a satellite cannot be repaired in orbit, the MTTF is the average life expectancy after which a replacement satellite must be launched for continued experimentation. Where in-orbit repair may be done, the MTTF is the average expected operating life after each repair. By adding repair delay to the MTTF, the time required for a complete operation-failure-repair cycle can be approximated.

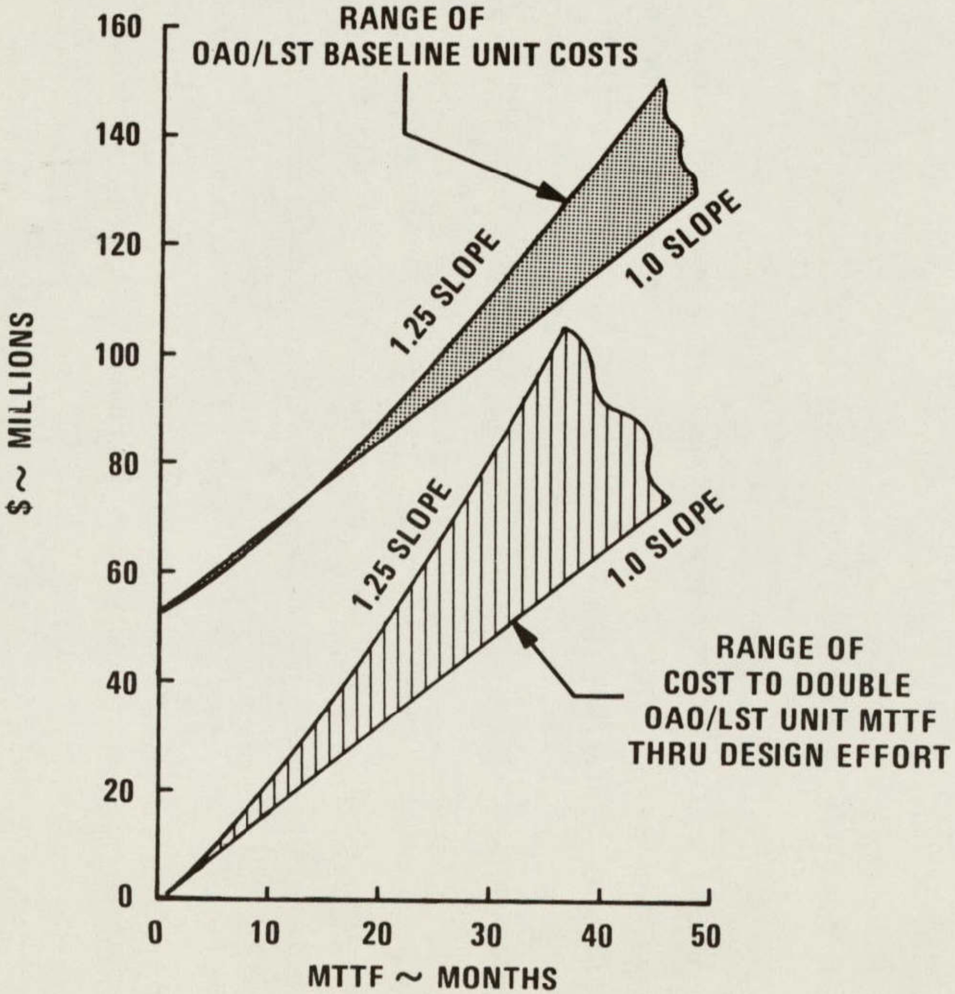

Figure 4-8. Cost Effectiveness of Shuttle Repair

4.5.1 Program Inputs

PERCOM inputs are:

- Program costs for baseline Shuttle assisted OAO/LST
- Baseline MTTF level
- Cost vs. MTTF slope for replaceable subsystems
- A range of selected MTTF levels
- A range of selected Shuttle schedule delays

The program is actually run for combinations of MTTF and schedule delay.

4.5.1.1 Program Costs

The Grumman data base of OAO experience was utilized to provide estimates of the costs of various elements of the LST. With the exception of the structure, telescope and scientific instrumentation, the LST systems are the same type as that available as flight qualified for the OAO program. Therefore, the OAO subcontractor costs, systems design, integration, test and operations data was extrapolated to provide estimates for the LST program.

The program cost elements were then organized and used as inputs to the computer program (PERCOM). The cost data fell into three major categories as defined below.

4.5.1.2 Fixed Costs

Items in this category were assumed to have a fixed cost. This included: mission operations, experiment update flights, ground stations, facilities, structure, primary optics, test and support equipment, Titan interstage and shroud, Shuttle interfaces, and launch operations.

4.5.1.3 Not Assessed Variable Costs

Items in this category were assumed to have a variable cost. However, variations in their cost as a function of their cost drivers were not assessed at this time. For the purposes of this study their costs were assumed to be constant.

Items included are: engineering, thermal, S/C mechanisms, system integration, program management, reliability, quality acceptance, and experiments.

4.5.1.4 Variable Costs

Items in this category were assumed to have a cost which would vary with its mean time to failure (MTTF). Equipment in this category included: stabilization, electric power, communication and data handling, and the pneumatic subsystems.

4.5.1.5 Baseline MTTF Level

A baseline level of MTTF of 12 months was selected as representing the current level of full-up performance of current OAO systems. While a satellite might survive and function longer than that, its performance would be degraded.

4.5.1.6 Cost vs. MTTF Slope

As discussed earlier in this section, slopes of 1.0 and 1.25 were taken as the range of increase of cost with increasing MTTF.

4.5.1.7 Range of Selected MTTF Levels

In order to explore the impact of MTTF as a cost driver, it was parameterized to have a range of values from 3 months to 48 months. This range was selected to explore both "cheap" and advanced state-of-the-art hardware.

4.5.1.8 Range of Selected Shuttle Schedule Delays

While Shuttle turn-around is projected at two weeks, the total delay between a known failure and the Shuttle's visit may be much longer. To test the impact of this program variable, a range of delays from two weeks up to two years was used.

4.5.2 PERCOM Outputs

The PERCOM computer program calculates the program data to provide equipment uptime and cost outputs. A typical computer output is shown in Fig. 4-9. It can be seen that the cost data falls into three categories; 1) non-recurring, 2) recurring and 3) operational.

PERCOM output includes: total program cost, viewing time (uptime) in years, uptime ratio in years, total number of equipment failures in 15 years, and the cost of Shuttle repair flights additional to that required to update experiments.

SHUTTLE SCHEDULE DELAY.. 1.5
TOTAL SYSTEM MTTF....... 12.0
VAR. SUBSYSTEM SLOPE.... 1.00

	SHUTTLE-MAINTAINED PROGRAM (3 SPACECRAFT)-NOT OPTIMIZED	NON-RECURRING	RECURRING	OPERATIONS
1	STRUCTURE	20150000.	30649216.	
2	ENGINEERING	17500000.	2250126.	
3	STABILIZATION	770620.	20475984.	
4	THERMAL	2120000.	2910971.	
5	S-C MECHANISMS	3520000.	2721483.	
6	ELECTRIC POWER	356190.	8980571.	
7	* PRIMARY OPTICS	3300000.	8000878.	
8	COMM. & DATA HANDLING	2125532.	13800008.	
9	PNEUMATICS	15370.	2983483.	
10	TEST & SUPPORT EQUIPMENT	4669540.	2070634.	
11	PROGRAM MANAGEMENT	2533000.	7119000.	
12	SYSTEM INTEGRATION	944000.	2448698.	
13	RELIABILITY	111600.	133800.	
14	QUALITY ACCEPTANCE	1445220.	5820000.	
15	TITAN INTERSTAGE	582000.	670000.	
16	* TITAN SHROUD	0.0	1000000.	
17	SHUTTLE INTERFACES	20910000.	1997000.	
18	TRAINERS & SIMULATORS	3110400.	100000.	
19	* EXPERIMENTS A & B	5000000.	39000000.	
20	GROUND STATION	3251000.	800000.	
21	* NEW COMPUTERS	4550000.	0.0	
	LAUNCH OPERATIONS			
22	* LV-TITAN	0.0	22500000.	
23	* LV-SHUTTLE	0.0	10000000.	
24	S-C SUPPORT	0.0	4950000.	
25	* FACILITIES	1347012.	362826.	
26	* SHUTTLE UPDATE FLIGHT	0.0	15000000.	
27	* EXPERIMENT UPDATE	0.0	39000000.	
28	* G.S.F.C. & OTHER	0.0	60000000.	
29	ORBITAL OPERATIONS			9000000.
	G & A CHARGEABLE	84114400.	110889872.	
	G & A	10850753.	14304787.	1160999.
	SUBTOTAL	94965152.	125194656.	
	NON-G & A SUBTOTAL	14197012.	194863680.	
	TOTAL	109162160.	320058112.	10160999.
	*NO G & A CHARGE			
			TOTAL	439380992.
	COST OF ADD'L SHUTTLE REPAIR FLTS			32222208.
	GRAND TOTAL			471603200.

NO. OF FAILURES.... 12.44
UPTIME (YEARS)..... 12.44
UPTIME RATIO....... 0.83

Figure 4-9. PERCOM Program Output (Typical)

5. ANALYSIS OF RESULTS

5.1 CARPET PLOT TECHNIQUE

Outputs of the PERCOM computer program, when plotted, form a series of intersecting families of curves or carpets as described in this section.

The baseline LST program calls for 6 launches to provide a program uptime of 9.5 years at a total program cost of $640 million.

The LST program with Shuttle availability calls for the launch of one prototype on a Titan booster, with subsequent vehicle launch, refurbishment and repair flights performed by the Shuttle. A comparison of the Titan-launched and Shuttle assisted programs appears in Fig. 5-1.

5.1.1 Carpet Plot Format

The basic format for OAO/LST program carpet plots appears in Fig. 5-2. The ordinate is total program cost, broken down into fixed, variable but not assessed, and assessed variable cost categories as shown. On this graph, the abscissa is program uptime or total viewing time available. The total viewing time available for the LST program is the summation of the individual viewing periods. The average length of a viewing period is equal to the MTTF.

5.1.2 Constant MTTF Curves

MTTF's considered for the vehicle varied from 3 months to 48 months. At a constant MTTF, an increase in program uptime is gained by Shuttle revisits. Each Shuttle revisit increases the program uptime by one MTTF and increases the program cost by the cost of a Shuttle flight. A line of constant Shuttle schedule delay (1.5 months) is shown in Fig. 5-2. This line indicates the maximum uptime obtained from the maximum number of operating cycles that can be accomplished in a 15 year program.

The plot can be divided into two separate and distinct areas, in each of which, one particular cost driver predominates. From 3 month MTTF to the lowest cost line (9-12 months), the cost of Shuttle revisits exerts the greatest effect. Beyond the minimum cost line, cost of increasing MTTF dominates.

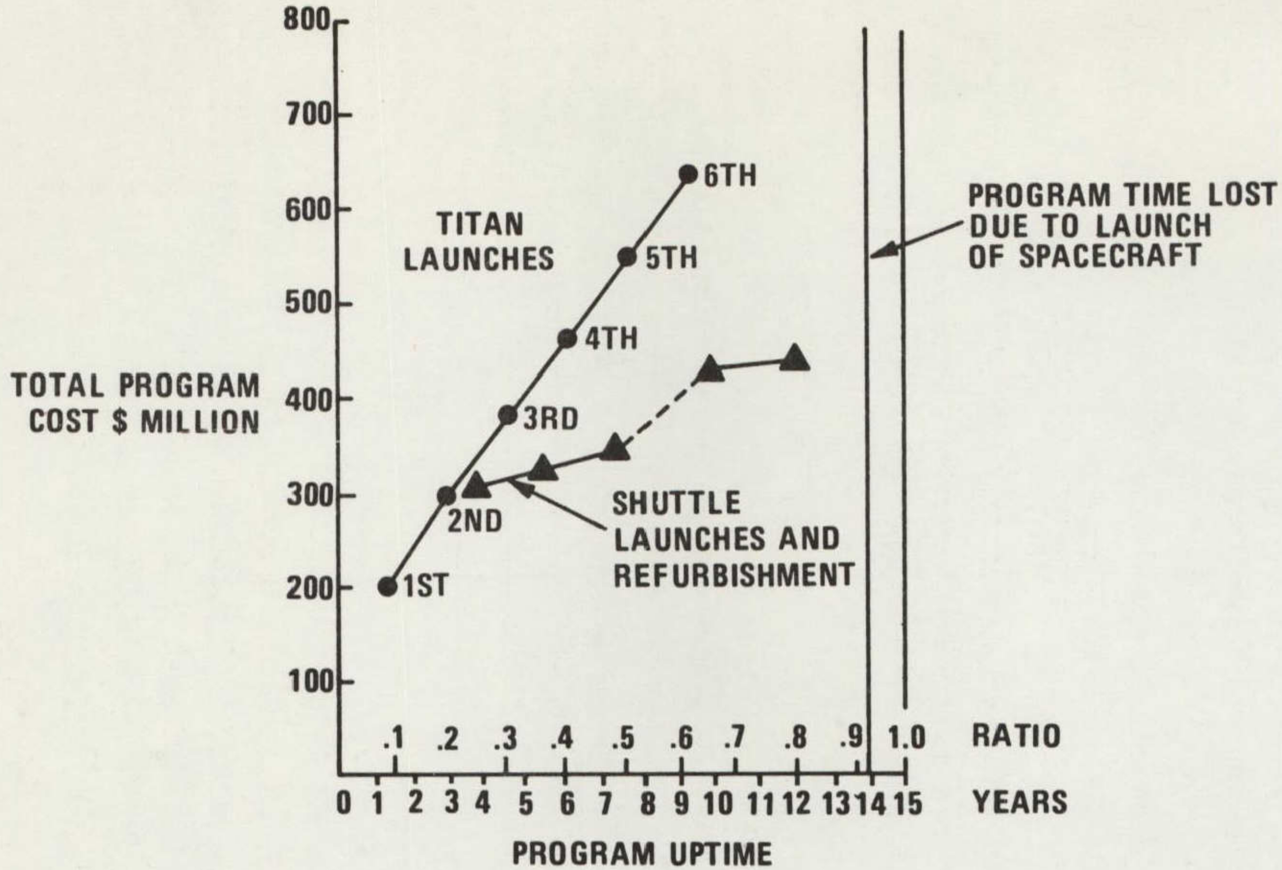

Figure 5-1. OAO/LST Cost Comparison With/W/O Shuttle

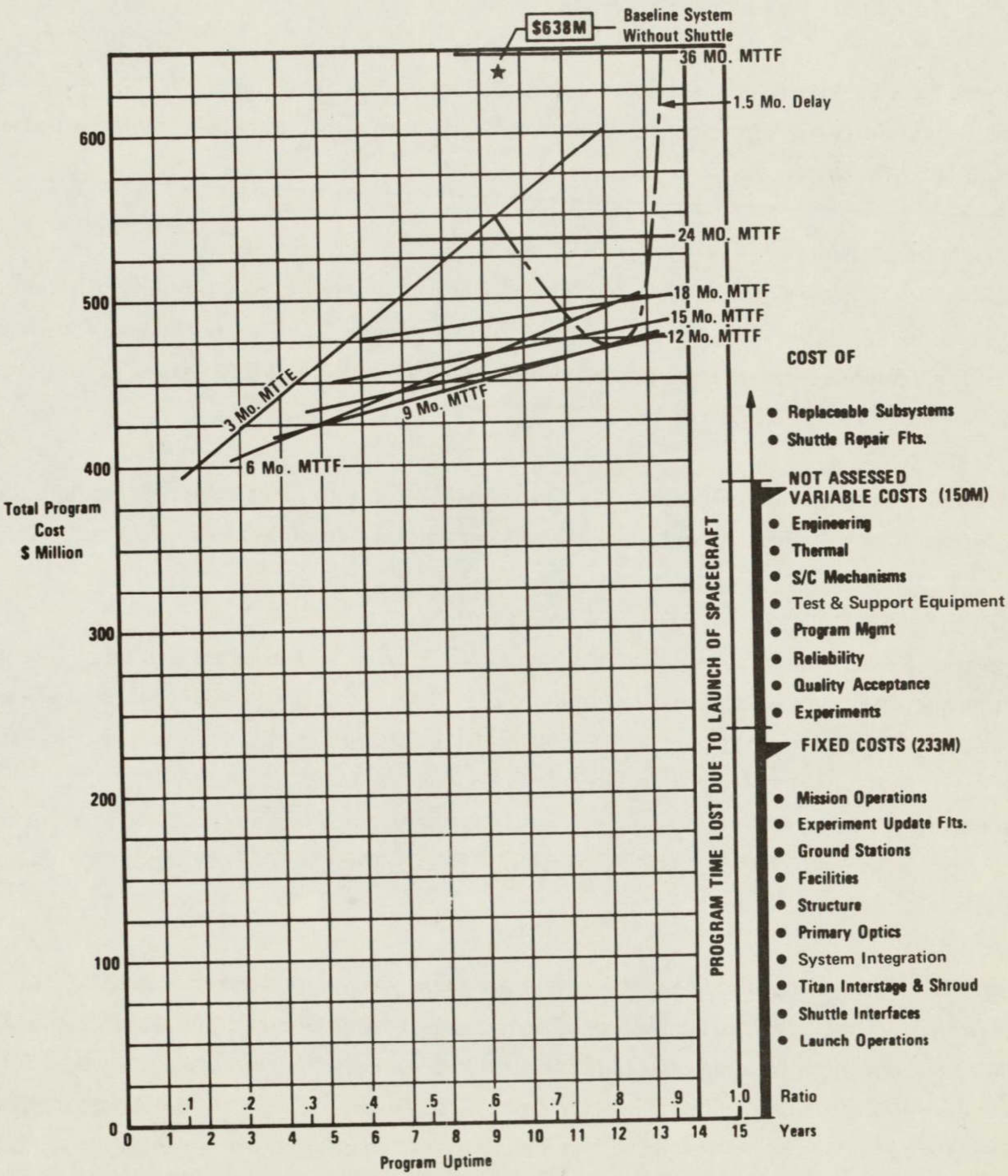

Figure 5-2. OAO/LST Performance & Cost
$ vs MTTF Slope - 1.0
12 Mo. MTTF Base Cost

At the lowest MTTF considered (3 months) the large number of repair/maintenance visits adds heavily to program cost. As the MTTF is increased, the reduction in number, and thereby cost, of Shuttle flights outweighs the increase in cost resulting from increasing MTTF through design. This yields lower program costs.

However, at a certain point the balance shifts. The cost of increasing MTTF through design begins to rise faster than the reducing cost of Shuttle trips falls, thereby yielding increasingly higher program costs.

5.1.3 <u>Shuttle Schedule Delay Lines</u>

Shuttle schedule delays which varied from a low of 0.5 months to a maximum of 24 months were considered. The shortest Shuttle delay of 0.5 months resulted in the highest program uptime for each MTTF. As the schedule delay is increased from this value, both uptime and program costs are reduced.

The period represented by Shuttle delay is devoted not only to Shuttle turn-around, but also includes payload preparation and loading, and administrative delay.

5.2 RESULTS INTERPRETATION

The graph of each line of constant Shuttle schedule delay runs through a low or saddle point denoting the minimum cost program for that delay. This minimum also occurs at specific values of MTTF and system uptime, thereby setting values for all of the major cost drivers.

As seen in Fig. 5-3, with increasing uptime, the envelope of the minimum cost program shifts from a 3 month MTTF up to a 12 month MTTF. The value of the minimum program cost rises at the same time.

If a specific value of uptime is selected as a program goal, the programs available to achieve that uptime are represented by all points on the line clearly, increasing or decreasing MTTF from the minimum cost point results in a higher program cost. Lower MTTF programs require shorter schedule delays and more flights to achieve the required uptime; while higher MTTF's allow longer delays, but use increasingly more expensive hardware. It is important to note the concentration of MTTF lines around the trace of saddle points. This indicates that program costs and cost driver values are relatively insensitive to moderate variations in MTTF about the optimum. Since the optimum MTTF's in the area of interest approximate current experience, it may be concluded that the minimum cost,

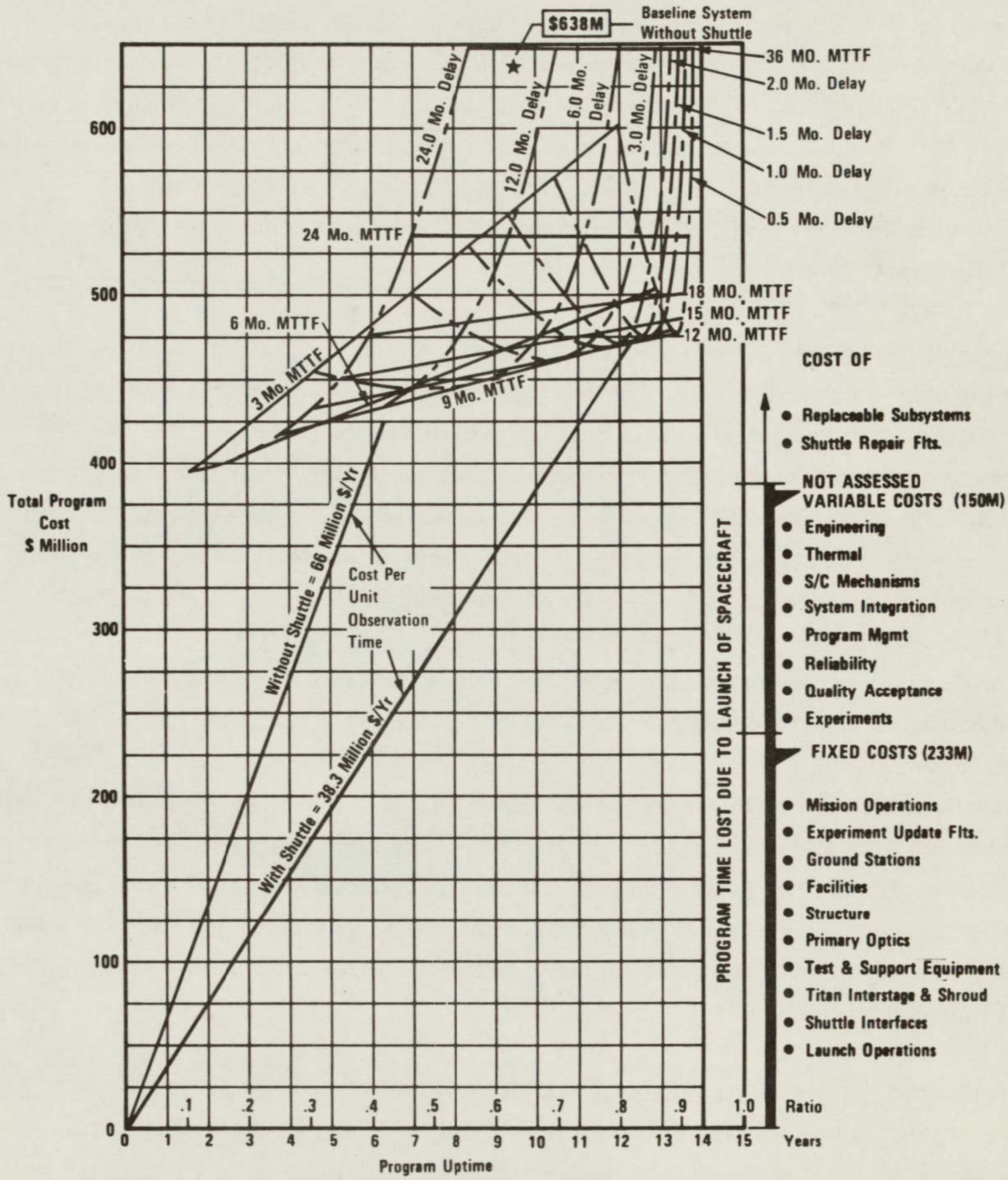

Figure 5-3. OAO/LST Performance & Cost
$ vs MTTF Slope - 1.0
12 Mo. MTTF Base Cost

maximum performance OAO/LST program will utilize the Shuttle and will require no advance in the MTTF state-of-the-art beyond current capability and design experience. The attendant reduction in program cost and performance risk is clear. Further, if the desired MTTF is not achieved in practice, a measurable increase in program cost at the lower MTTF and a shorter Shuttle delay will still yield the same uptime. Alternatively, for the same program cost, some uptime may be sacrificed. Another conclusion to be drawn directly from the graph on Fig 5-3 is that Shuttle delays of up to 6 months will not materially reduce program effectiveness or alter cost.

The graph of Fig. 5-4 is an expanded plot of the carpet plot area of Fig. 5-3, and is presented for clarity purposes. Fig. 5-5 is a replot of Fig. 5-4, but with number of flights as the abscissa. It therefore represents a 90° rotation of the prior plot. In this graph as in prior ones, the bunching of delay lines illustrates the system's relative insensitivity to variation in Shuttle schedule delay. To present a total picture of the OAO/LST program, an uptime scale has been added; however it applies only in the shaded area of the curve. That shaded area traces the path of saddle points giving the lowest cost programs.

In order that the Shuttle-launched system can achieve the same degree of science that is offered by the six instrument changes on the Titan-launched system, the same number of instrument changes is required. This means that in addition to the initial Titan launch, five additional Shuttle flights are required. From Fig. 5-5 it may be concluded that with the higher MTTF's above 24 months or with the lowest uptime programs less than six flights are required. Using six flights as a minimum program to achieve equal experiment capability, it may be seen that MTTF's much in excess of 24 months are unusable for a program with a maximum uptime of 14 years; and that for the lower MTTF programs, delays up to 12 months are acceptable.

The graph of Fig. 5-6 is presented to illustrate the impact of a sharper slope to the cost of MTTF. Where on Fig. 5-4 the 36-month MTTF program cost of almost \$650 million, the 1.25 slope of Fig. 5-6 produces a 36-month MTTF program cost of over \$770 million. The minimum cost programs, however, remain within \$20M of the corresponding points on the former graph. As can be seen, then, the most cost effective program is relatively insensitive to the slope of the cost vs. MTTF curve since the use of current technology (MTTF

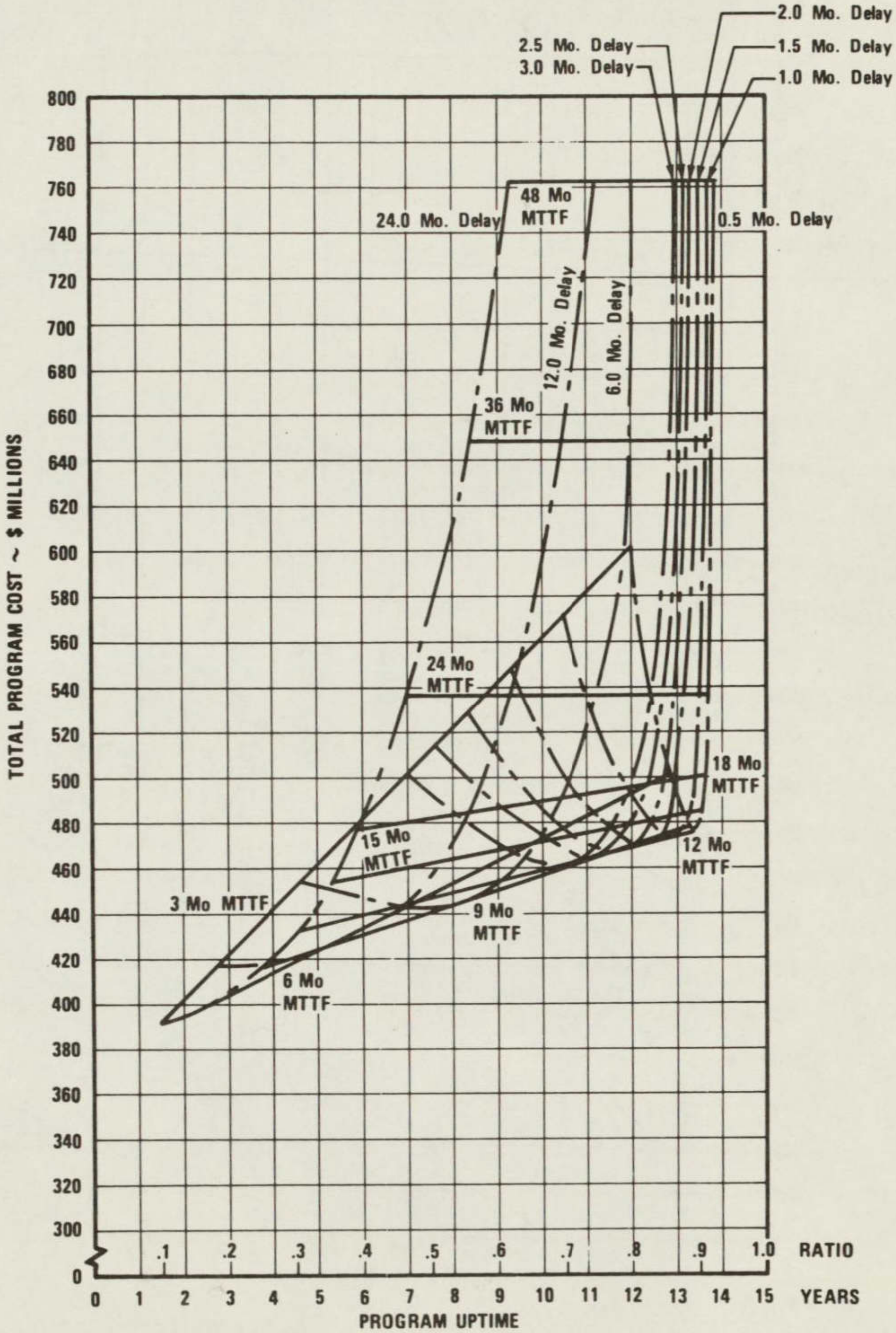

Figure 5-4. OAO/LST Performance & Cost
$ vs MTTF Slope = 1.0

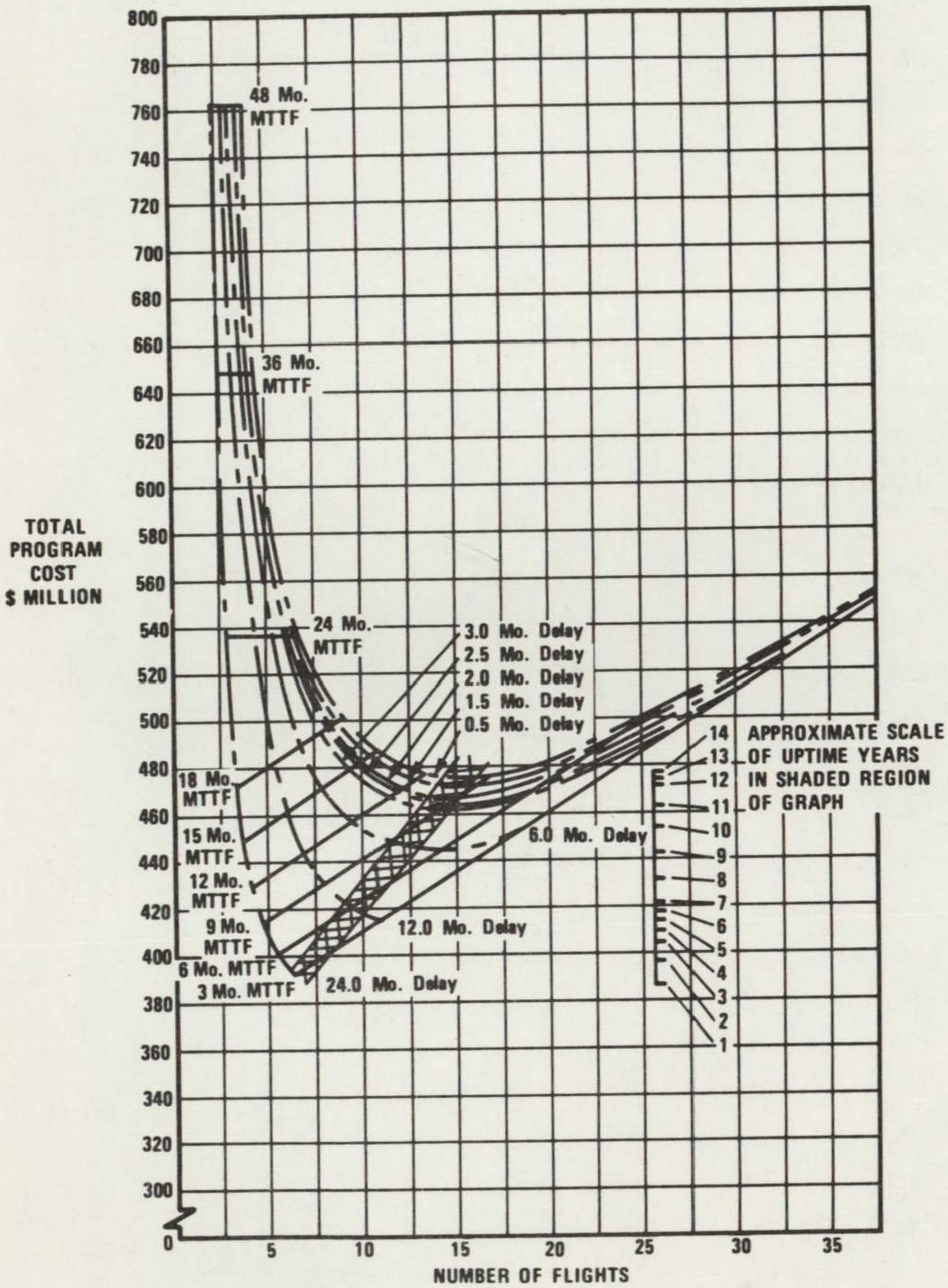

Figure 5-5. OAO/LST Performance & Cost
$ vs MTTF Slope = 1.0

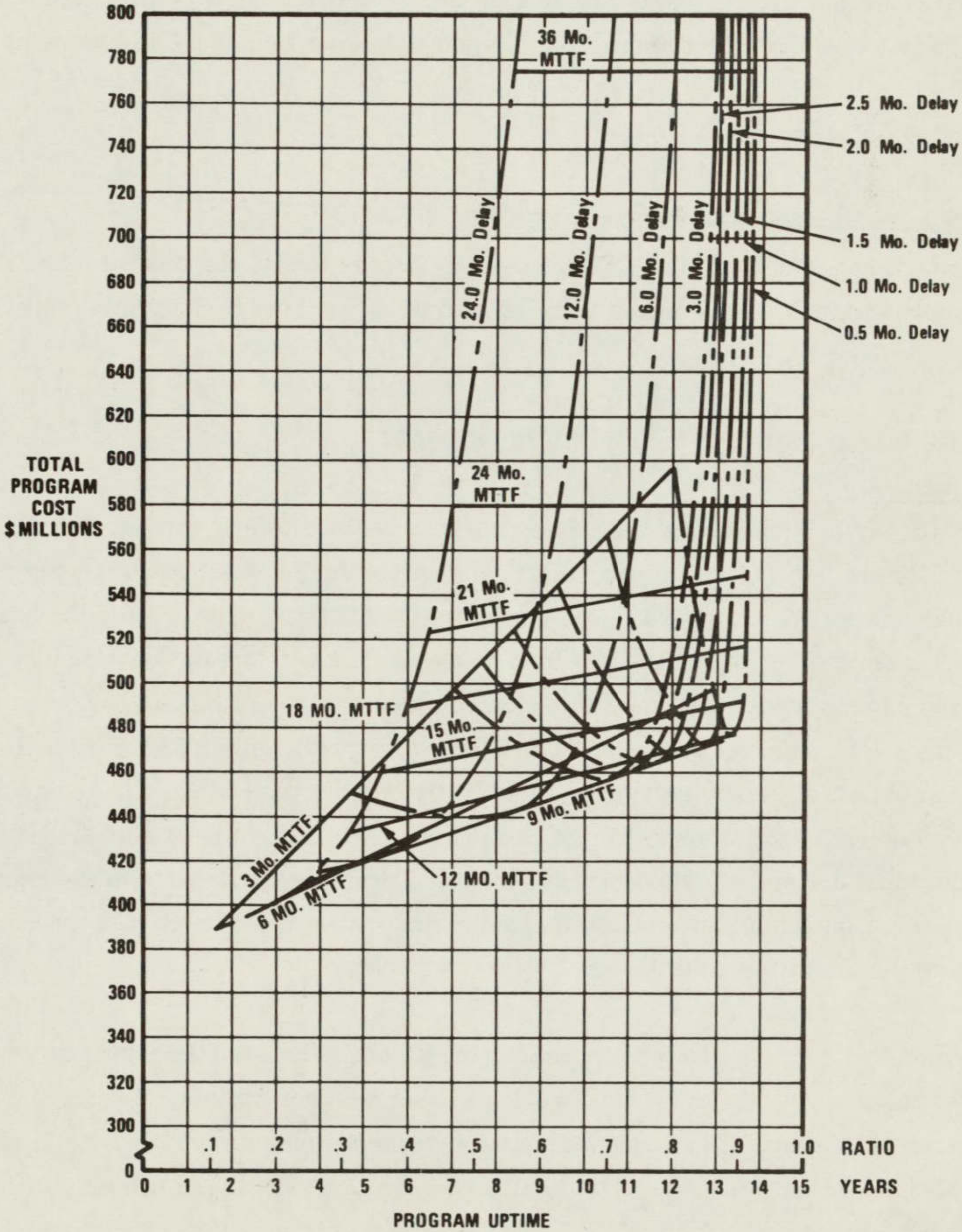

Figure 5-6. OAO/LST Performance & Cost
$ vs MTTF Slope = 1.25

expectations ranging from 9 to 18 months, based upon actual flight data) yields minimum program costs and it is only in advanced technology programs that variations in MTTF cost appear. Further, if an investment is to be made, it should go into higher performance equipment and not longer life. Clearly, even a halving of present lifetime expectancy from 12 months down to 6 does not significantly impact program cost to achieve the same uptime.

Fig. 5-7 is the 90° rotation of Fig. 5-6.

5.2.1 Sensitivity to Variable Shuttle Revisit Costs

OAO/LST unit cost and required MTTF are relatively insensitive to the cost of a Shuttle revisit. Fig. 5-8 illustrates the insensitivity of total program cost to Shuttle revisit cost variation.

5.3 ECONOMIC RESULTS WITH AND WITHOUT SHUTTLE

5.3.1 Study Results

The results of the study, comparing OAO/LST program costs with and without shuttle, are summarized in Figure 5-9. These costs reflect a program for continuing astronomy as discussed in paragraph 1.3 and represent 6 spacecraft and 6 Titan launches for the baseline program with 3 spacecraft with 1 Titan and 2 Shuttle launches with 3 additional Shuttle revisits for resupply and experiment changes for the economic comparison of the Shuttle program. Making these experiment changes with the Shuttle program represents a $91 million savings as compared to achieving the same degree of flexibility without the Shuttle. This savings is summarized in Figure 5-10. Comparing the two programs in Figure 5-11 shows that large amounts of additional uptime, or spacecraft operational time, is achieved with the Shuttle program for a small increment in increased costs compared with the large increase in costs required without the Shuttle to gain the same degree of uptime.

Figure 5-12 compares the most important characteristics for the OAO/LST programs with and without the Shuttle. In all cases, the Shuttle enables a higher uptime, lower program cost, and a lower MTTF with its attendant reduction in technological complexity and risk. Although the carpet plot analysis shown in detail in Section 5 shows that a minimum cost program is achieved with a 12 month MTTF satellite, or at current state of the art achievement for MTTF's, we have used a 24 month MTTF satellite for comparative purposes since this satellite will represent some degree of degraded performance and is more consistent with the resultant degraded performance that will accrue to the 36 month MTTF requirement for the OAO/LST program without the Shuttle.

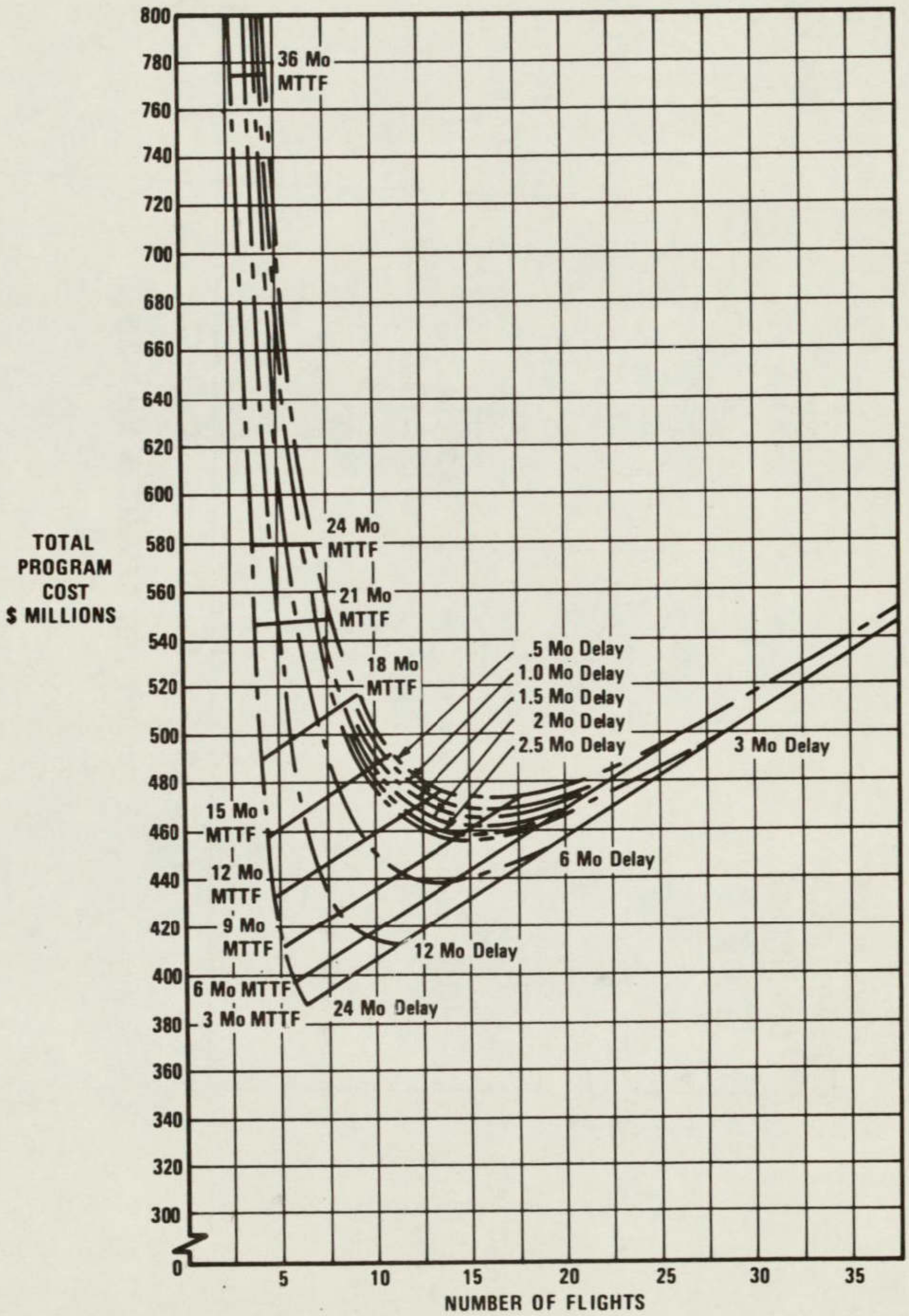

Figure 5-7. OAO/LST Performance & Cost
$ vs MTTF Slope = 1.25

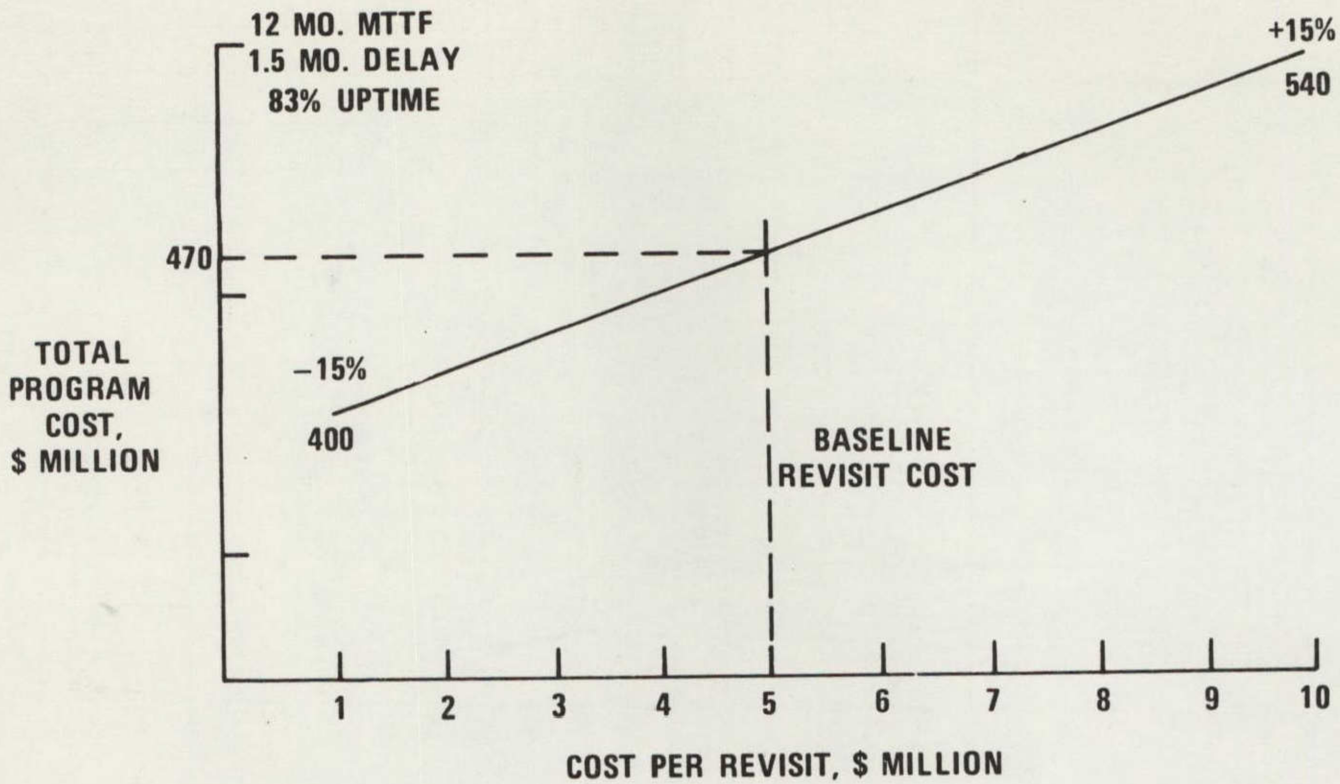

Figure 5-8. OAO/LST Low Sensitivity to Variable Shuttle Revisit Costs

	Shuttle, $M		Titan, $M		Savings Total, $M	Savings %
Spacecraft		368		503	137	21
Launch Vehicles – Titan	22.5	(1)	135	(6)		
– Shuttle	25.0	(5)	–			
Resupply Mech – Shuttle	24.5		–			
Subtotal		72.0		135	63	10
Total		440		638	200	31

Figure 5-9. OAO/LST Cost Savings with Shuttle

	Without Shuttle	With Shuttle
Spacecraft	73.6	–
Launch Vehicle	22.5	5.0
Instrumentation	13.0	13.0
Total	$ 109.1 M	$ 18.0 M
Response Time	3 Yr Interval	On Demand
Cost Savings		$ 91.0 M

Figure 5-10. OAO/LST Experiment Change Cost Comparison

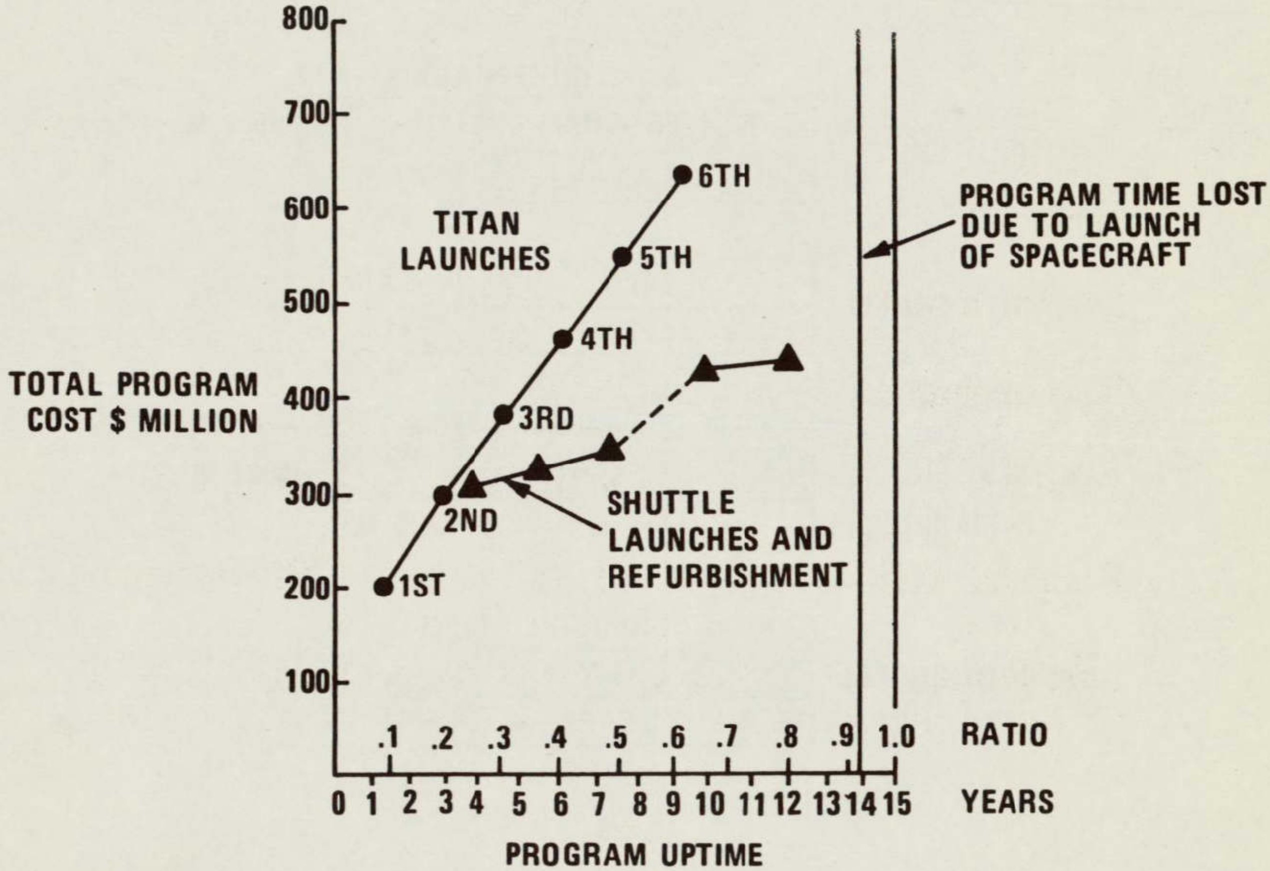

Figure 5-11. OAO/LST Cost Comparison With and Without Shuttle

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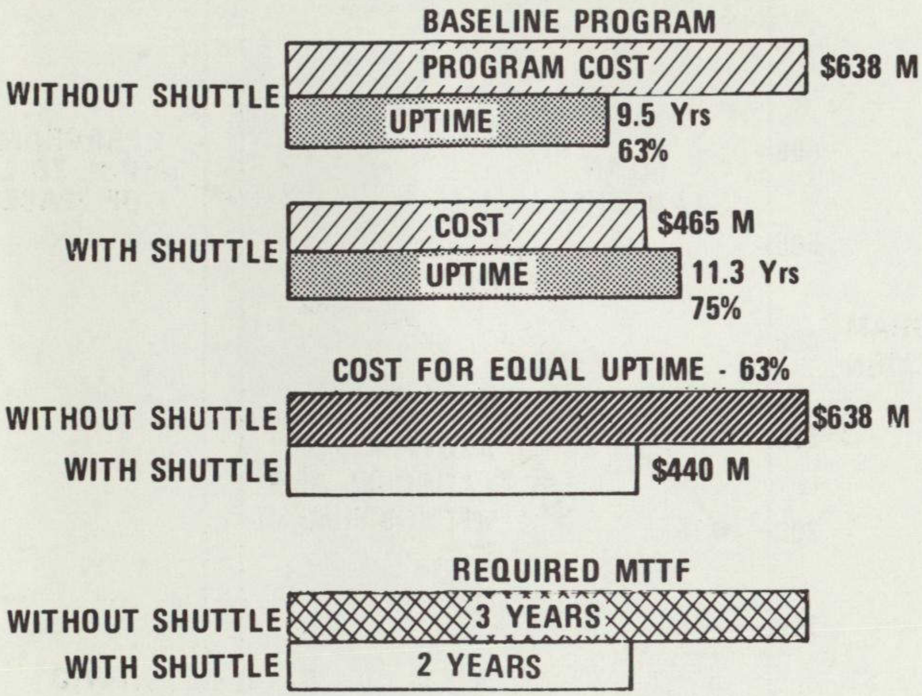

Figure 5-12. OAO/LST Program Comparison

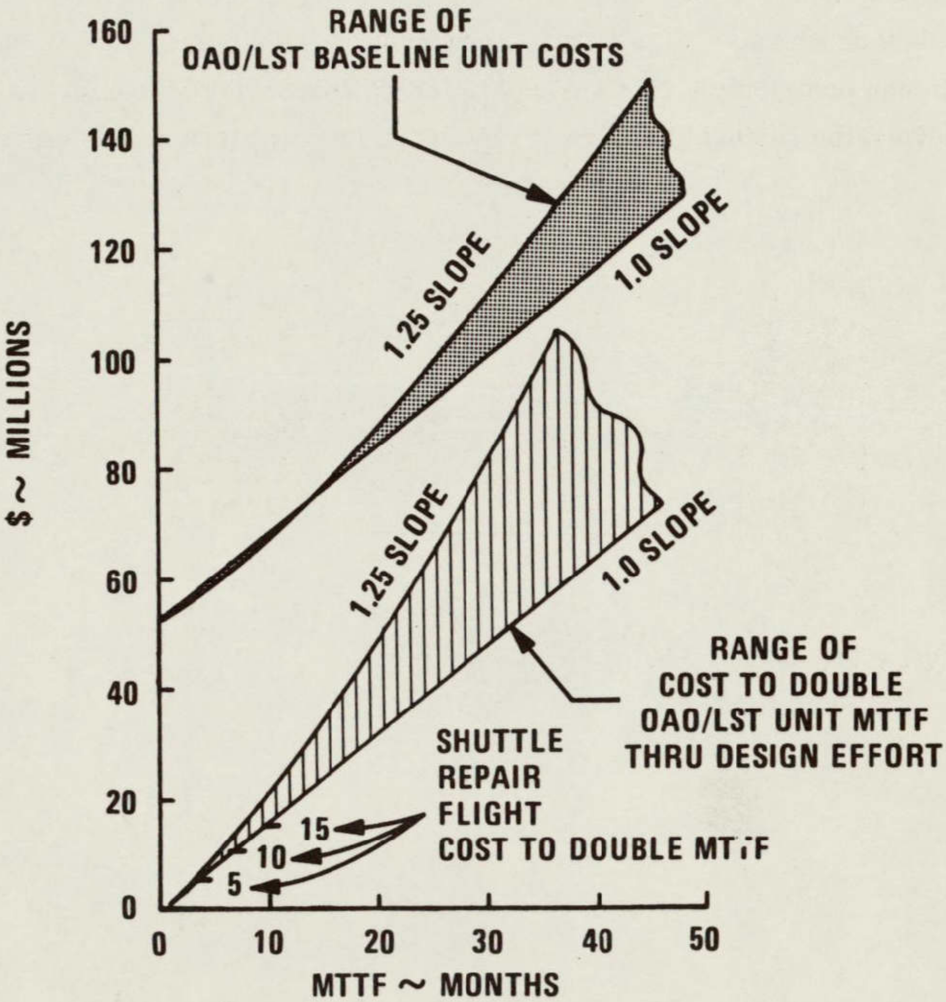

Figure 5-13. Cost Effectiveness of Shuttle Repair

Figure 5-13 has been developed to show the relationship between Shuttle flight cost and the cost of increased satellite MTTF. Considering that each Shuttle revisit adds an increment of life equal to (1) MTTF, the cost of a Shuttle flight may then be compared to the cost of adding (1) MTTF through improved design and production. Since this means doubling the MTTF, the cost to double MTTF was taken from the upper set of curves and plotted to produce the lower set. The addition of various Shuttle flight costs defines levels of MTTF above which use of the Shuttle is economically preferable, and below which improved MTTF through design is best. From Figure 1-6 it can be seen that the Shuttle revisit costs can approach $20 million before it becomes cost effective to improve MTTF through design. This is true regardless of whether we use a 1.25 or a 1.0 power slope. This analysis has shown that the Shuttle program can contribute a cost savings to future spacecraft design and development that goes far beyond the savings that accrue due to the low cost transportation provided.

6. STUDY CONCLUSIONS

6.1 STUDY CONCLUSIONS

This study has identified several important economic advantages that will accrue to future scientific spacecraft programs that had not been realized before. In summary these are:

- Spacecraft savings of $137M
- Launch vehicle savings of $63M
- Program savings of $200M
- Shuttle allows experiment change for $91M savings
- Annual funding requirement comparable to OAO program
- Schedule delays of up to 6 months due to Shuttle availability or turnaround time do not significantly affect OAO/LST Program costs
- Shuttle availability makes current spacecraft technology adequate for OAO/LST mission
- Shuttle flight cost can go to $20M before state-of-the-art MTTF improvements become cost effective for today's OAO-LST mission
- Tomorrow's mission requirements can be met with more cost effectiveness through Shuttle repair rather than design improvements for increased MTTF
- Shuttle availability minimizes uncertainties in OAO/LST performance and total program cost
- Low OAO/LST program sensitivity to Shuttle payload capacity
- Increased science capability through instrumentation update
- Orbital resupply enables higher uptime ratios
- Observation cost per year reduced
- The ability to repair failures allows the more demanding missions of the 1970's to be met with existing technology, thereby
    - Allowing initial program estimates to be established with confidence at acceptable levels
    - Preventing cost growth
    - Offering management options for cost reductions over prior experience by
        - Reducing the number of missions required
        - Reducing costs by lowering MTTF requirements
        - Re-use of retrieved hardware
- Spacecraft program cost reductions of 27% are achieved for LST based upon existing technology
- Abort capability with Shuttle eliminates mission loss due to spacecraft or L/V failure

7. RECOMMENDATIONS FOR FUTURE EFFORT

7.1 STUDY RECOMMENDATIONS

This study has indicated that a more detailed future effort should be instituted that would examine the economic impact of OAO/LST point design optimization utilizing the shuttle. It is therefore recommended that the following tasks be pursued:

Task 1	Subsystem Level of Redundancy vs. Cost Optimization
Task 2	Subsystem Level of Maintenance Optimization
Task 3	System Dynamic Simulation - To determine Impact of Design Guidelines
Task 4	Assess Impact of Additional Cost Variables

Task 1 will involve the use of a dynamic programming technique which will evaluate the possible combinations of cost and number of redundant units in each LST subsystem. The program will then select the subsystem design alternative or set of alternatives which produce the greatest probability of success for a given cost.

Task 2 includes the analysis of cost versus the level, (module, blackbox, or subsystem) at which in-space maintaining will be performed. Various levels of maintenance for each LST subsystem will be investigated and their cost impact evaluated to insure that the LST is resupplied at the most cost effective level.

Task 3 will involve an actual simulation of a 15 year LST mission under various resupply, delay, MTTF, level of redundancy, and level of maintenance conditions. This simulation will allow for a cost evaluation of the impact of sets of design guidelines simultaneously.

Task 4 includes an in-depth assessment of the other cost elements as well as the variable costs which were previously assessed. The sensitivity of cost to reductions in MTTF or design life specifications will be quantitatively evaluated. This will include the reduction of design analysis, test and program schedule. The cost savings associated with retrieval and refurbishment, which should be of significance due to the large investment in spacecraft and telescope cost elements, will also be evaluated in this task.